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Technical Report

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FAILURE ANALYSIS OF THE LOWER REAR BALL JOINT ON THE HIGH-MOBILITY MULTIPURPOSE WHEELED VEHICLE (HMMWV)

AUGUST 1988

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Tests of the HMMWV M1037 S-250 Shelter Carrier conducted at Aberdeen Proving Grounds (APG) and the Nevada Automotive Test Center (NATC) have resulted in failures of the lower rear ball joints. A three-dimensional computer model of the HMMWV Shelter Carrier, including all suspension and steering components, was developed using the DADS methodology to calculate the position, velocity, and acceleration as well as the forces and torques at critical points on the vehicle and at suspension elements while the vehicle is negotiating the NATC course. The results give the magnitude of the forces acting on the joint and also provide the scenario of leading to the failure.

The joint angle between the ball joint stud and the ball joint housing was calculated to determine if an interference condition occurred.

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1.0. INTRODUCTION

This report prepared by the Analytical and Physical Simulation Branch of the System Simulation Division, U.S. Army Tank-Automotive Command (TACOM) details a dynamic analysis of the High-Mobility Multipurpose Wheeled Vehicle (HMMWV). Tests of the HMMWV M1037 S-250 Shelter Carrier conducted at Aberdeen Proving Grounds (APG) and at the Nevada Automotive Test Center (NATC) have resulted in failures of the lower rear ball joints. This ball joint connects the rear wheel assembly to the rear suspension lower control "A" arm. Failure of the joint causes the vehicle to become instantaneously inoperable.

The HMMWV dynamic response resulting from negotiating the bump course used in the NATC tests was analyzed. Analysis of the vehicle's dynamic response included the position, velocity, and acceleration of various parts of the vehicle as well as the forces that act upon the vehicle. Position, velocity, and acceleration provide the complete dynamic history of the vehicle while the forces and torques are used to determine component loading.

Analysis of the HMMWV employs the Dynamic Analysis and Design System (DADS) computer-based methodology to generate and solve the vehicle's equations of motion.

2.0. OBJECTIVE

The objective of the dynamic analysis was to use a threedimensional computer model of the HMMWV M1037 S-250 Shelter Carrier using the DADS methodology to calculate the position, velocity, and acceleration as well as the forces and torques at critical points on the vehicle and at the suspension elements while the vehicle is negotiating an obstacle course.

The obstacle course at NATC was chosen for the dynamic simulation because of the failures of the rear ball joints while negotiating this course and because the course was surveyed, which gave an accurate geometrical course description. Seven obstacles ranging from 13 to 22 inches high, spaced approximately 1-1/2 to 2 wheel-base lengths apart, comprise the course. The vehicle speed just before entering the test course was approximately 15 miles per hour. This speed was also used during the simulation.

This analysis also calculated the joint angle between the ball joint stud and the housing to determine if interference occurred.

The simulation results provide a dynamic history of the vehicle response while negotiating the course. These results give the magnitude of the forces acting on the joint and also provide the scenario of events leading to the failure.

A static force analysis was also performed on the right rear suspension unit to determine the magnitude of the joint forces under a given loading condition. Forces applied to the wheel included a combination of vertical, lateral, and longitudinal forces acting at the wheel and road interface. The static analysis results provide the sensitivity of the rear suspension unit to externally applied forces.

3.0. CONCLUSION

The dynamic simulation results showed that both the front and the rear wheels left the ground frequently while the HMMWV negotiated the NATC course. Large forces were generated in the suspension elements when the vehicle returned to the ground. Furthermore, greater forces were produced at the right rear suspension unit because the center of gravity (CG) location is rearward and to the right of the vehicle. The large forces are generated when the shock absorber exceeds the travel limits, causing metal-to-metal contact within the internal shock components. Also at this time the tire run-flat insert makes contact with the tire carcass due to large tire deflections. When these events occur the suspension unit is essentially locked up, thus generating large reaction forces.

Simulation results also showed that the largest tensile and shear forces occurred within the right rear ball joint when the right rear wheel strikes the ground after clearing the first obstacle. Video tapes of the tests at NATC showed failure to occur at the same location within the course.

The analysis also showed that the angle between the ball joint stud and the housing did not exceed the recommended angular motion limits and no interference occurred.

The static analysis showed that the rear suspension units are very sensitive to a combination of forward longitudinal forces and outward lateral forces along with the vertical support forces applied to wheel. Under these conditions the magnitude of the shear force component in the lower ball joint increases greatly with only small increases in the externally applied forces. This loading condition could occur when the inside rear wheel leaves the ground while negotiating a turn or a bump and simultaneously power is applied to the wheels. When the wheel returns to the ground, vertical and lateral forces would be created along with a forward longitudinal force due to the power applied to the wheels. Under these conditions large shear forces would be generated in the lower ball joint.

4.0. RECOMMENDATIONS

Based upon the simulation results the following recommendations will improve the life of the ball joint:

- Modify the shock absorber characteristics within the hydraulic bump stop region to provide more dissipative forces. This in turn will decrease the frequency of exceeding the shock travel limits, decrease the velocity of the suspension prior to reaching metal-to-metal contact, and decrease the impact reaction forces if metal-to-metal contact does occur.

- In addition to, or as an alternative to the previous recommendation, install rubber bump stops external to the shock absorber will also decrease the velocity of the suspension elements before the shock makes metal-to-metal contact.

- Modify the size or the stiffness of the run-flat insert. If the run-flat radius were smaller, then the probability of the tire carcass making contact with the device during large tire deflections would decrease. A less stiff or "softer" device would generate smaller reaction forces when contact does occur.

- Distribute the load such that the center of gravity is located closer to the vehicle center thus distributing the forces more evenly between the suspension units.

- Increase the size of the ball joint stud.

- Change the material composition and hardness of the ball joint stud.

5.0. DISCUSSION

5.1. Vehicle Description

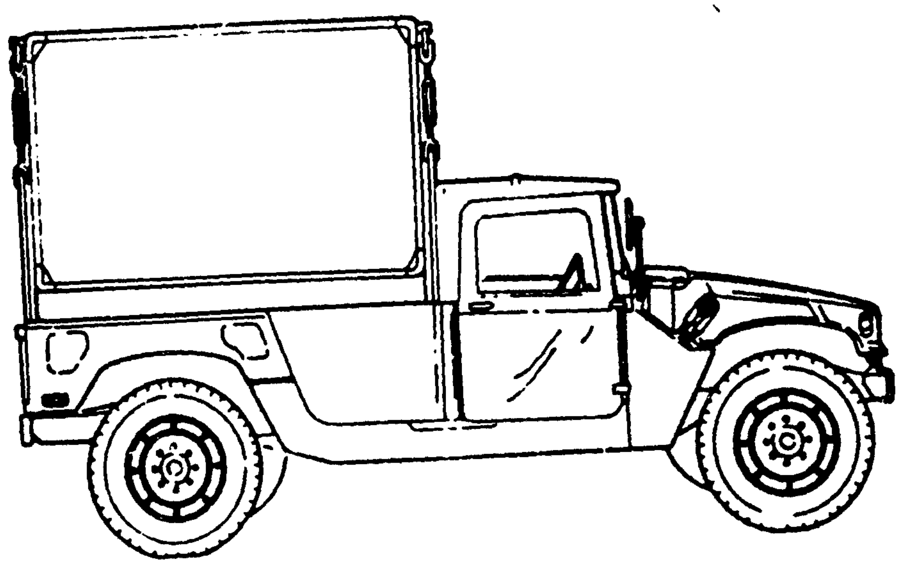
The HMMWV is designed to provide combat, combat support, and combat service support roles. The HMMWV is capable of accepting various body configurations to accommodate weapon systems, 1-1/4-ton utility cargo, and ambulance roles. A high degree of mobility is required in both off-road and on-road travel. The 4X4 wheeled common chassis includes a 145-hp diesel engine, automatic transmission, power steering, and run-flat tires. Table 5-1, supplied by AM General, gives the HMMWV weight characteristics for each model.

The purpose of the M1037 and M1042 models is for securing and transporting the S250 electrical equipment shelter. The M1042 model, which has a winch, can be used for recovery operations. Figure 5-1 shows the M1037 and M1042 models. The M1037 model was used for this analysis.

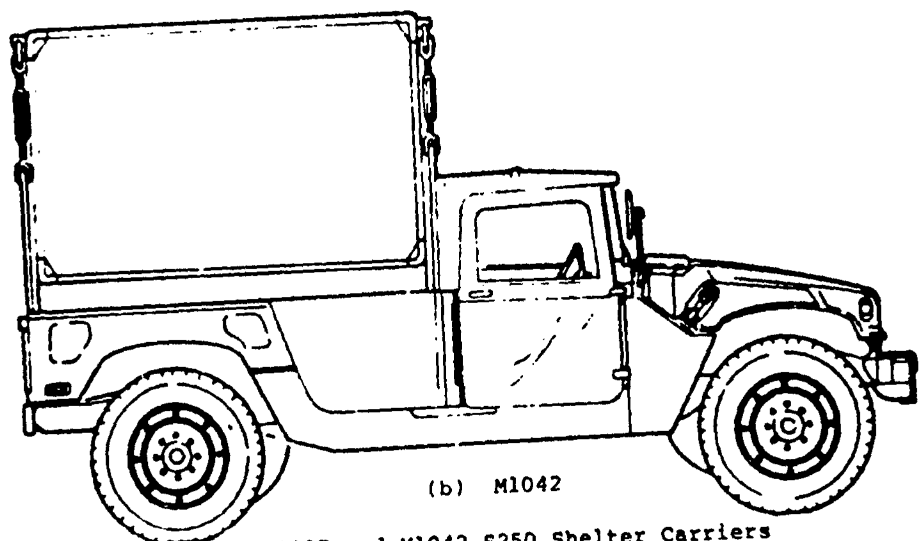
5.2. Vehicle Properites

Table 5-1. HMMWV Weight Characteristics Summary

Model No.	Model Description	Center of Gravity At Curb Weight CGX	CGY	CGZ	Curb Weight Actual	Curb Weight Production Maximum	Front Axle Weight Rating Curb	Front Axle Weight Rating GVW	Rear Axle Weight Rating Curb	Rear Axle Weight Rating GVW	Allowable Payload	Contract GVW
M998	Truck, Utility: Cargo/Troop Carrier WO/W	57.7"	1.2"	29.9"	5062 Lbs	5200 Lbs	2900 Lbs	3350 Lbs	2300 Lbs	4350 Lbs	2500 Lbs	7700 Lbs
M1038	Truck, Utility: Cargo/Troop Carrier W/W	55.0"	1.2"	29.7"	5109 Lbs	5327 Lbs	3052 Lbs	3400 Lbs	2275 Lbs	4300 Lbs	2373 Lbs	7700 Lbs
M966	TOW Missile Carrier: Basic Armor WO/W	63.0"	1.1"	32.0"	5913 Lbs	6051 Lbs	3111 Lbs	3550 Lbs	2940 Lbs	4650 Lbs	2149 Lbs	8200 Lbs
M1036	TOW Missile Carrier: Basic Armor W/W	61.2"	1.1"	32.6"	6040 Lbs	6170 Lbs	3253 Lbs	3700 Lbs	2925 Lbs	4500 Lbs	2422 Lbs	8200 Lbs
M1045	TOW Missile Carrier: Supplemental Armor WO/W	64.1"	1.0"	32.5"	6364 Lbs	6430 Lbs	3266 Lbs	3725 Lbs	3172 Lbs	4675 Lbs	1962 Lbs	8400 Lbs
M1046	TOW Missile Carrier: Supplemental Armor W/W	62.4"	1.0"	32.3"	6401 Lbs	6500 Lbs	3407 Lbs	3850 Lbs	3190 Lbs	4800 Lbs	1830 Lbs	8400 Lbs
M1025	Armament Carrier: Basic Armor WO/W	62.1"	1.1"	33.1"	5022 Lbs	5960 Lbs	3112 Lbs	3685 Lbs	2040 Lbs	4515 Lbs	2240 Lbs	8200 Lbs
M1026	Armament Carrier: Basic Armor W/W	60.3"	1.1"	32.9"	5049 Lbs	6087 Lbs	3280 Lbs	3840 Lbs	2820 Lbs	4360 Lbs	2113 Lbs	8200 Lbs
M1043	Armament Carrier: Supplemental Armor WO/W	63.2"	1.0"	32.8"	6273 Lbs	6411 Lbs	3300 Lbs	3961 Lbs	3111 Lbs	4439 Lbs	1909 Lbs	8400 Lbs
M1044	Armament Carrier: Supplemental Armor W/W	61.5"	1.0"	32.6"	6400 Lbs	6530 Lbs	3445 Lbs	4092 Lbs	3093 Lbs	4300 Lbs	1862 Lbs	8400 Lbs
M1037	S-250 Shelter Carrier WO/W	61.6"	1.1"	28.4"	5206 Lbs	5424 Lbs	2834 Lbs	3362 Lbs	2590 Lbs	5298 Lbs	3236 Lbs	8660 Lbs
M1042	S-250 Shelter Carrier W/W	59.6"	1.1"	28.3"	5413 Lbs	5551 Lbs	2991 Lbs	3307 Lbs	2560 Lbs	5273 Lbs	3109 Lbs	8660 Lbs
M1037-MBE	S-250 Extended Shelter Carrier WO/W	*	*	*	Lbs	Lbs	Lbs	Lbs	Lbs	Lbs	Lbs	8800 Lbs
M1069	Truck, Utility: L119 Prime Mover WO/W	60.0"	1.2"	31.8"	5232 Lbs	5370 Lbs	2090 Lbs	3800 Lbs	2400 Lbs	5600 Lbs	4030 Lbs	9400 Lbs
M997	Maxi-Ambulance 4-Litter, Basic Armor	70.7"	1.3"	30.0"	7054 Lbs	7180 Lbs	3235 Lbs	*3860 Lbs	3946 Lbs	*5340 Lbs	1920 Lbs	*9100 Lbs
M996	Mini-Ambulance 2-Litter, Basic Armor	70.5"	.90"	35.1"	6622 Lbs	6748 Lbs	3063 Lbs	3673 Lbs	3605 Lbs	4987 Lbs	1912 Lbs	8660 Lbs
M1035	Soft Top Ambulance 2-Litter	58.9"	1.3"	22.3"	5150 Lbs	5297 Lbs	2098 Lbs	3350 Lbs	2407 Lbs	4390 Lbs	2403 Lbs	7700 Lbs



(a) M1037



(b) M1042

Figure 5-1. HMMWV M1037 and M1042 S250 Shelter Carriers

5.2.1. Weight. The simulated HMMWV M1037-MSE S-250 Shelter Carrier had a reported total gross vehicle weight (GVW) of 8,719 pounds. AM General Division of LTV Aerospace and Defense Company, manufacturers of the vehicle, provided the weights of the suspension components. Table 5-2 gives the weight of the chassis sprung mass and the weight of the suspension elements.

5.2.2. CG. The CG location for the HMMWV M1037-MSE S-250 Shelter Carrier as located from behind the front wheels, the vehicle center, and the ground are given in Table 5-3. By subtracting the weight of each suspension component such as the upper and lower control arms and the wheels, the CG location for the chassis sprung mass was calculated. The calculated chassis sprung mass CG location is given in Table 5-4.

5.2.3. Moment of Inertia. Exact measurements for the moment of inertia for the HMMWV M1037-MSE S-250 Shelter Carrier have not been conducted. However, moment of inertia measurements for the TOW weapons carrier with the TOW system (GVW 6,393 lbs) were conducted during Group 1 vehicle tests. The roll, pitch, and yaw moments of inertia are given in Table 5-5. The moment of inertia for the chassis sprung mass will be less than the total vehicle moment of inertia because the chassis sprung mass does not include the suspension elements. Since the HMMWV shelter carrier has a GVW greater than the TOW weapon carrier, the moments of inertia presented in Table 5-5 were used for the shelter carrier chassis sprung mass.

5.3 Suspension

5.3.1. Suspension Description. Four independent double "A" arm suspension units are used on the HMMWV, one for each wheel. Both the upper "A" arm and the lower "A" arm are attached at the chassis frame and at the wheel assembly. Rear radius rods and front tie rods, connected between the chassis frame and the wheel assembly, control the static toe angle and the wheel steer direction. A coil spring and a shock absorber are mounted between the chassis and each lower control arm. Figures 5-2 through 5-7 show the suspension geometry and dimensions for each front and rear suspension units and the steering components.

5.3.2. Wheel Kingpin Inclination. The kingpin inclination angle is defined as the angle in front elevation between the steering axis and vertical. The kingpin offset is defined as the horizontal distance at the ground in front elevation between the point where the steering axis intersects the ground and the center of tire contact.[1]

Kingpin inclination angle provides a self-aligning moment when a wheel is steered. During steering a wheel is turned around the kingpin axis, which causes both sides of the vehicle to lift. This lifting action creates an unstable condition. When the vehicle tries to regain the low, stable position, a self-aligning moment is created. The moments generated are zero at zero steer angle, and with a steer angle, the

Table 5-2. Weights for Vehicle Components

Item	Weight
Chassis Spring Mass	7,747 pounds
Lower Control Arm	36 pounds each
Upper Control Arm	12 pounds each
Wheel Assembly	195 pounds each
Total gross vehicle weight	8,719 pounds

Table 5-3. Vehicle Center of Gravity Location

Direction	Location
Fore-Aft	81.70 inches
Right Side	0.52 inches
Vertical	46.00 inches

Table 5-4. Chassis sprung mass center of gravity location

Direction	Location
Fore-Aft	83.800 inches
Right Side	0.585 inches
Vertical	49.684 inches

Table 5-5. Vehicle moments of inertia

Axis	Inertia
Roll	13,320 lb-inch-sec**2
Pitch	52,680 lb-inch-sec**2
Yaw	56,280 lb-inch-sec**2

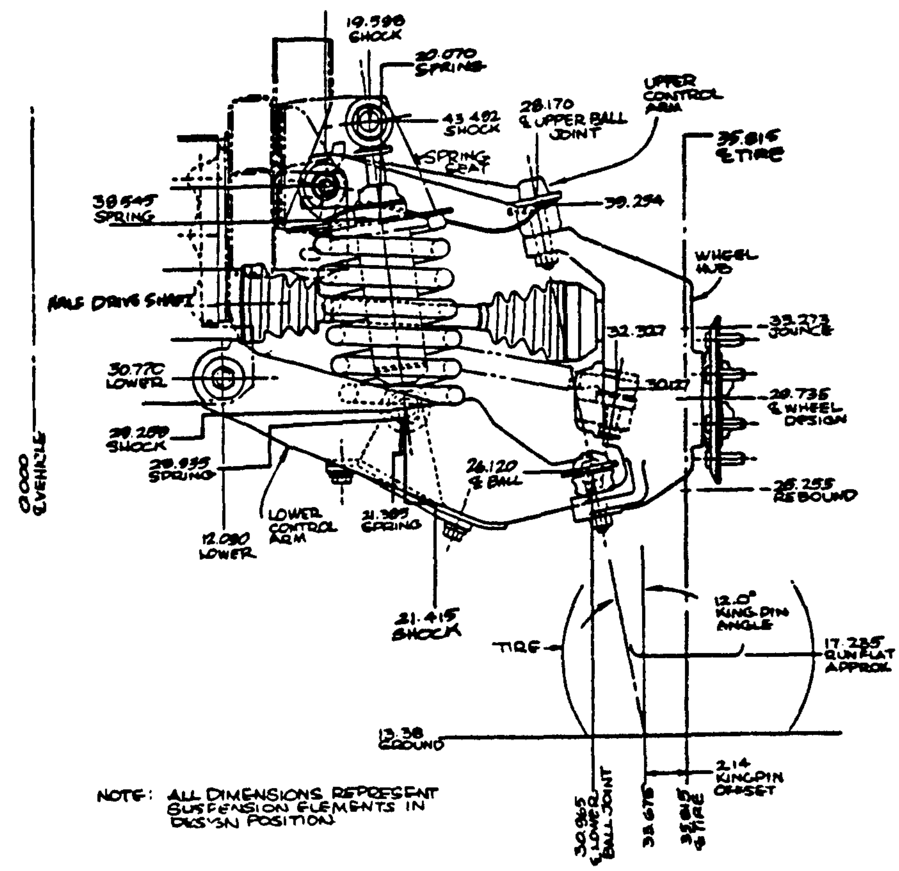
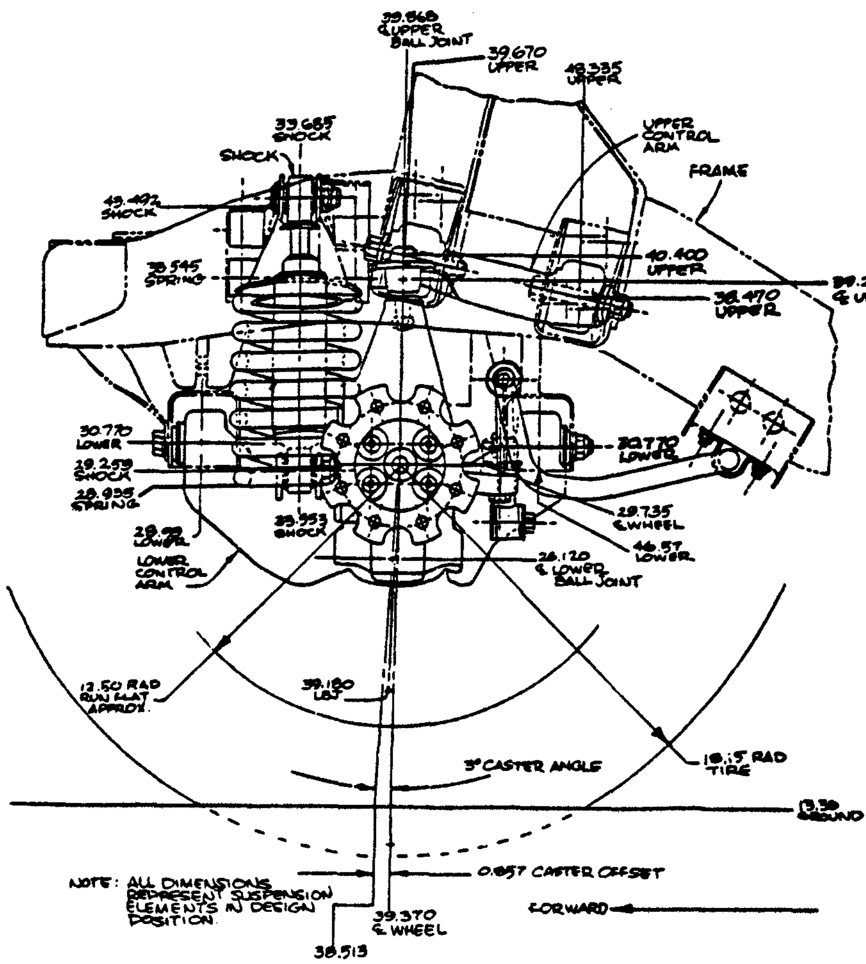


Figure 5-2. Front Left Suspension, Front View



FRONT LEFT SUSPENSION
LEFT SIDE VIEW

Figure 5-3. Front Left Suspension, Left Side View

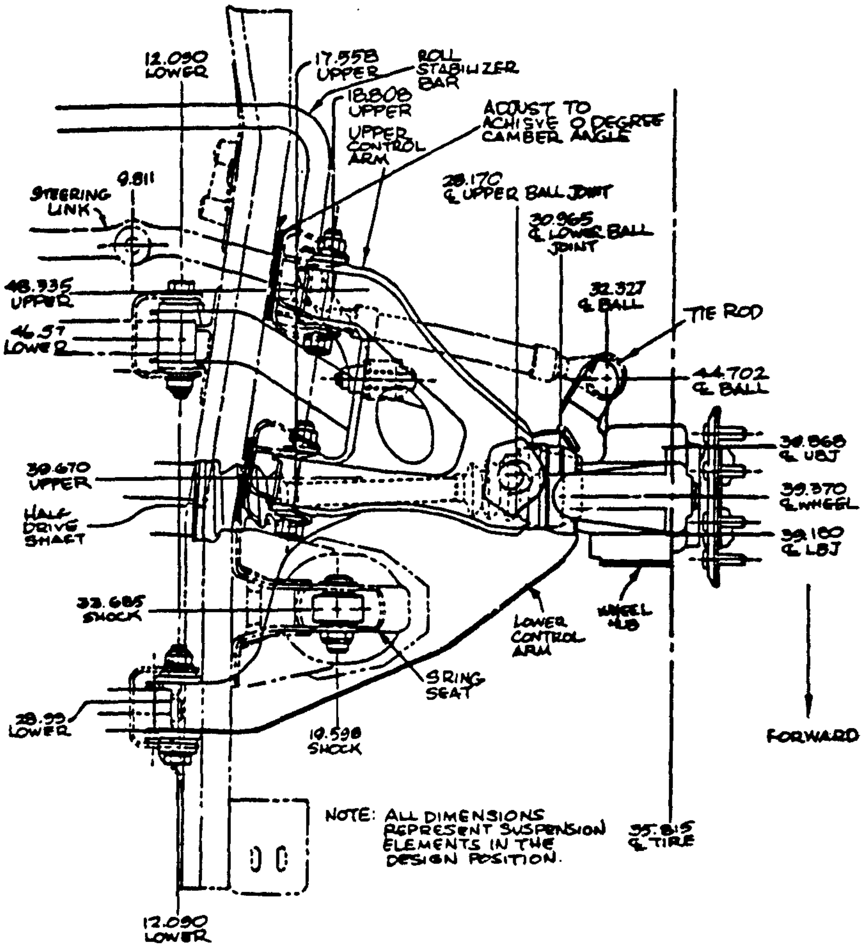


Figure 5-4. Front Left Suspension, Top View

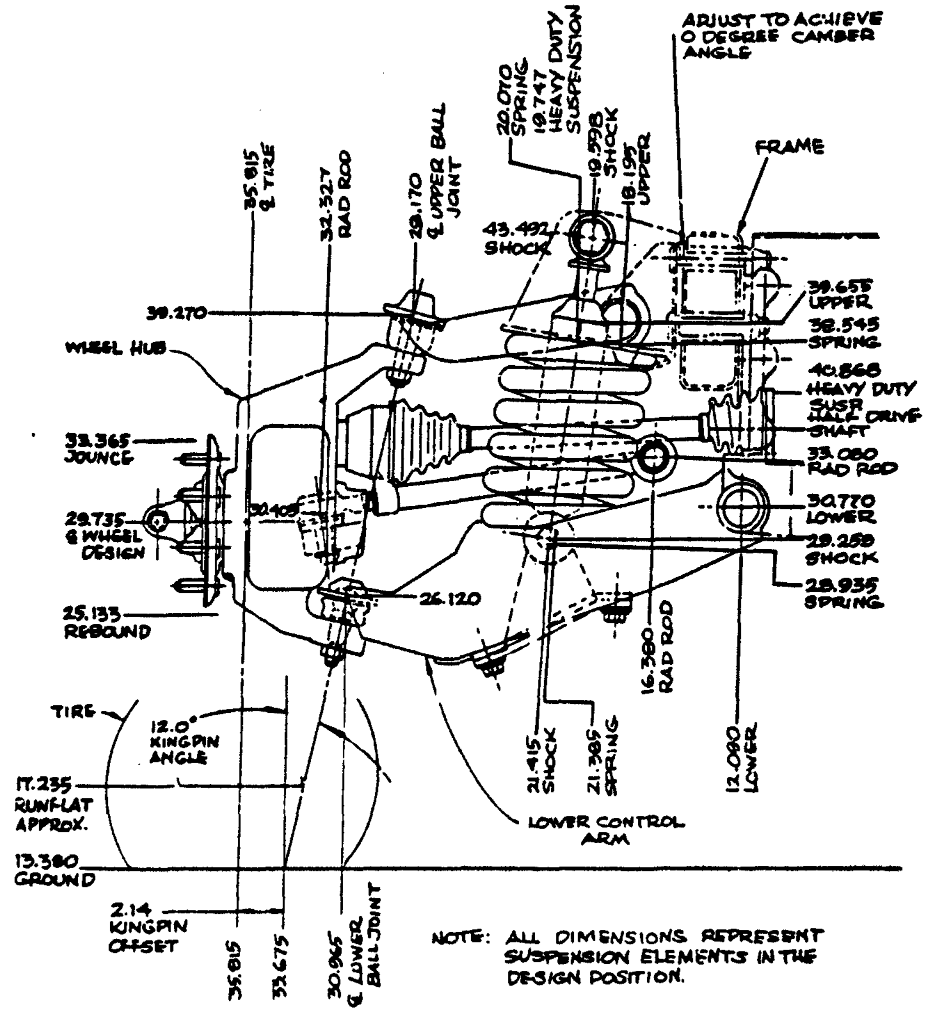


Figure 5-5. Rear Left Suspension, Rear View

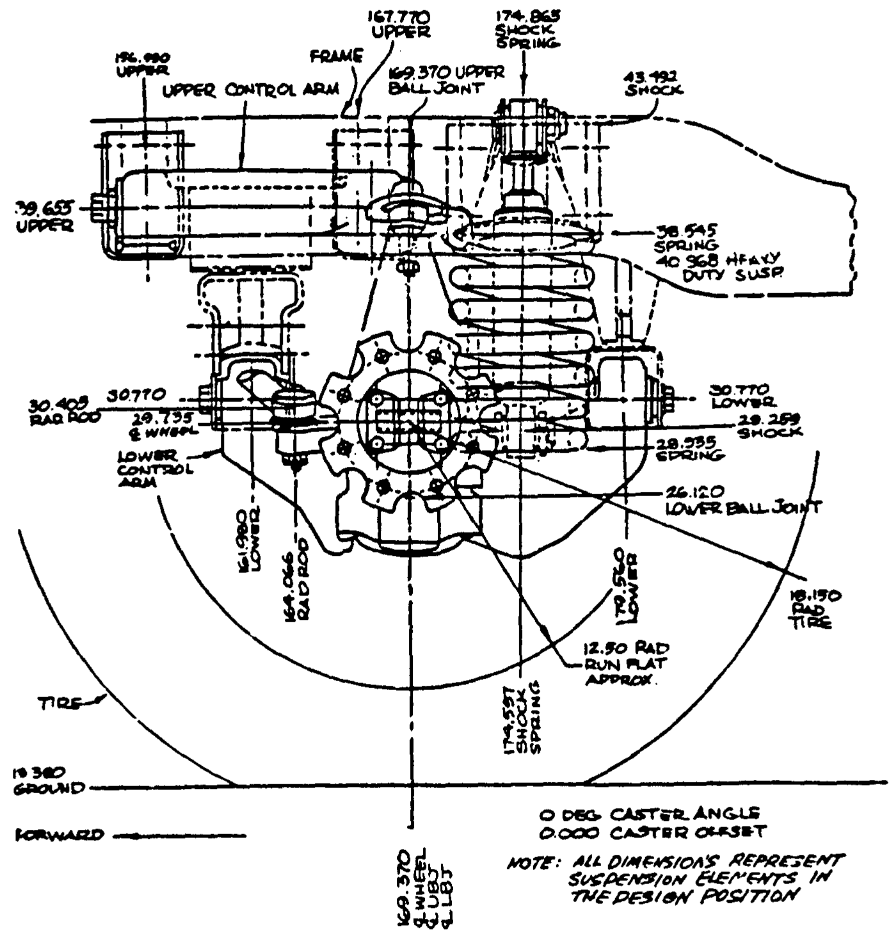


Figure 5-6. Rear Left Suspension, Left Side View

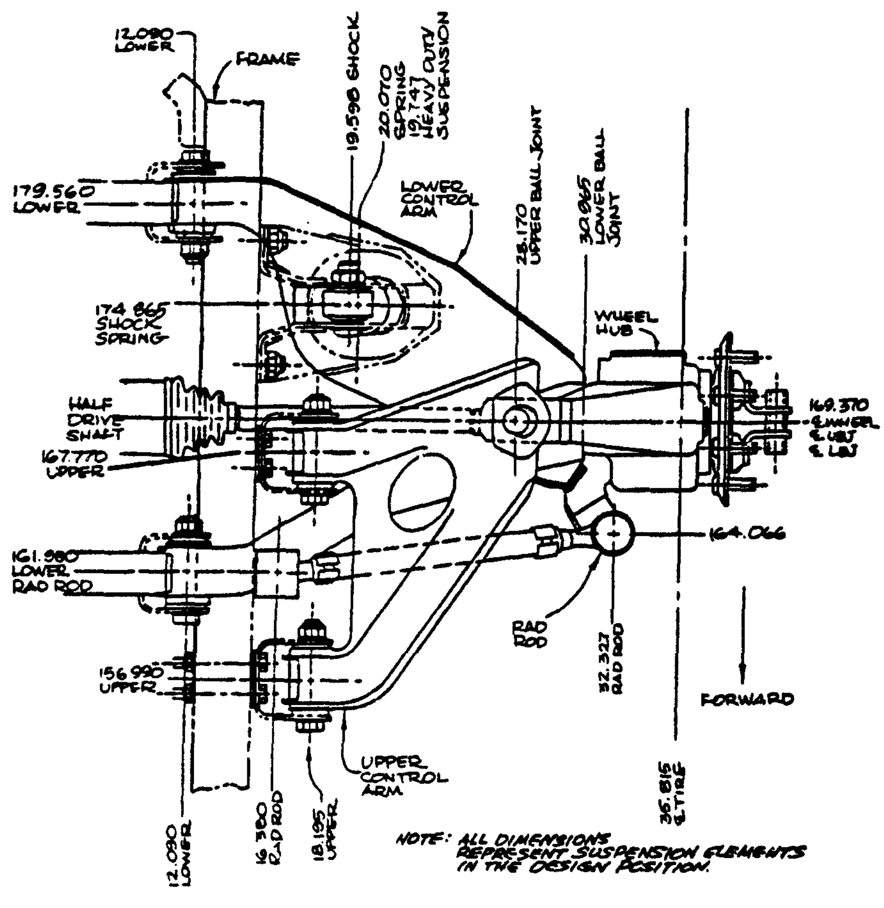


Figure 5-7. Rear Left Suspension, Top View

moments on both the left and right wheels act together. The net centering moment is proportional to the load but independent of the left and right load distribution.[2]

The actual turning center of a steered wheel is at the kingpin offset point. Steering motion of the wheel around this point requires both wheel sliding and rotation.[3]

The kingpin inclination angle and the kingpin offset for the HMMWV front and rear suspension units at the design position are given in Table 5-6.

5.3.3. Wheel Caster. Caster angle is defined as the angle in side elevation between the steering axis and vertical. Caster angle is considered positive when the steering axis is inclined rearward (in the upward direction) and negative when the steering axis is inclined forward.[4]

Caster offset is defined as the distance in side elevation between the points where the steering axis intersects the ground and the center of tire contact. The offset is considered positive when the intersection point is forward of the tire contact center and negative when it is rearward.[5]

Caster is used for the self-aligning steering effect it produces. With an applied steer angle, one side of the axle lifts and the other side drops. This axle roll will cause the left and right wheel loads to vary with steer angle in an amount dependent on the roll stiffness at the axle and on other factors. The total caster restoring torque is symmetric about the zero steer angle point and would equal zero if no load imbalance on the wheels is assumed. The total torque at zero steer angle will not be zero if a load imbalance exists, and the vehicle will experience a steering "pull" in normal straight ahead driving. During normal cornering at a given speed, the load transfer to the outside wheel produces a torque, via the caster, which attempts to steer the vehicle into the turn.[6]

The caster angle and the caster offset for the HMMWV front and rear suspension units at the design position are given in Table 5-7. The tolerance on the caster angle given in Table 5-7 is plus or minus 1.5 degrees.

5.3.4. Wheel Camber. Wheel camber angle is defined as the inclination of the wheel plane to vertical. Camber angle is considered positive when the wheel leans outward at the top and negative when it leans inward.[7]

A cambered wheel would follow a circular rolling path if not restricted. However, the direction of travel of a cambered wheel on a vehicle deviates from its natural rolling path, creating a slip angle and consequently a lateral cornering force. Values of this force are relatively small.[8]

Table 5-6. Kingpin Angle and Kingpin Offset

Suspension Unit	Kingpin Angle	Kingpin Offset
Front	12 degrees	2.14 inches
Rear	12 degrees	2.14 inches

Table 5-7. Caster Angle and Caster Offset

Suspension Unit	Caster Angle*	Caster Offset
Front	3 degrees	0.857 inches
Rear	0 degrees	0.000 inches

*Tolerance on the Caster Angle is Plus or Minus 1.5 Degrees

The wheel camber angle has only secondary effects on the steering behavior of a vehicle. A camber angle can be chosen to achieve axial bearing loads and to change the kingpin offset distance. The selection of camber angle is normally dominated by tire wear. Too high a camber angle promotes excessive tire wear.[9]

The camber angle for the HMMWV front and rear suspension units at the design position are given in Table 5-8. The tolerance on the camber angle given in Table 5-8 is plus 1.50 degrees or minus 0.50 degrees.

The camber angle on the HMMWV is adjusted by inserting spacers between the chassis frame and the upper control arm mounting bracket. Adding spacers increases the camber angle while removing spacers decreases the camber angle.

5.3.5. Wheel Alignment. Static toe-in or toe-out of a pair of wheels at a specified wheel load or relative position of the wheel center with respect to the chassis sprung mass is the difference in the transverse distances between the wheel planes taken at the extreme rear and front points of the tire tread. When the distance at the rear of the wheel is greater, the wheels are "toed-in"; and where smaller, the wheels are "toed-out."[10]

The wheel toe angle combined with the vehicle drive direction forms a tire slip angle, creating a side-thrust capacity for absorbing side shocks from the road and eliminating steering wheel flutter known as "shimmy." Too-high toe-in angles result in excessive tire wear and high rolling resistance.[11]

The front toe-in alignment specifications and the rear toe-out alignment specifications shown in Table 5-9 and Table 5-10 respectively can be found in Technical Manual TM 9-2320-280-20, pages 8-13 through 8-22.

The wheel toe-in angle and toe-out angle can be calculated from the tire measurements explained in the Technical Manual and shown in Figure 5-8. The tire radius in the free condition is 18.15 inches.

The static toe-in and toe-out angles for the HMMWV front and rear suspension units at the design position are given in Table 5-11. The wheel toe-in angle and the wheel toe-out angle are used as input to the wheel body orientation angle (ANGLE.3) about the global Z axis. The effects of the wheel toe-in or toe-out angle can be seen in the tire slip angles and the resulting lateral forces and aligning torques on each wheel.

5.3.6. Springs. Constant rate coil springs are used in each suspension unit. The springs are placed between the lower control arm and the chassis frame. The spring attachment points are shown in Figures 5-2 through 5-7. Table 5-12 gives the spring usage for several vehicle models. The HMMWV M1037 S-250 Shelter Carrier has a heavy duty rear suspension unit and uses the heavy duty spring (5597913). The chassis

Table 5-8. Camber Angle

Suspension Unit	Camber Angle*
Front	0 degrees
Rear	0 degrees

*Tolerance on the Camber Angle is Plus 1.5 or Minus 0.5 Degrees

Table 5-9. Front Toe-In Alignment Specifications

Vehicle Model	Toe-In
M998, M1025, M1026, M1035 M1038, M1043, M1044	7/16 inch ± 1/8 inch (11mm ± 3 mm)
M966, M996, M997, M1036 M1037, M1042, M1045, M1046	5/16 inch ± 1/8 inch (8mm ± 3mm)

Table 5-10. Rear Toe-Out Alignment Specifications

Vehicle Model	Toe-Out
M998, M1025, M1026, M1035 M1038, M1043, M1044	7/16 inch ± 1/8 inch (11 mm ± 3mm)
M966, M996, M997, M1036 M1037, M1042, M1045, M1046	5/16 inch ± 1/8 inch (8mm ± 3mm)

Table 5-11. Static Toe Angle

Suspension Unit	Static Toe	Static Toe Angle
Front	Toe-In 7/16 inch	0.00430 radians
Rear	Toe-Out 7/16 inch	0.00430 radians

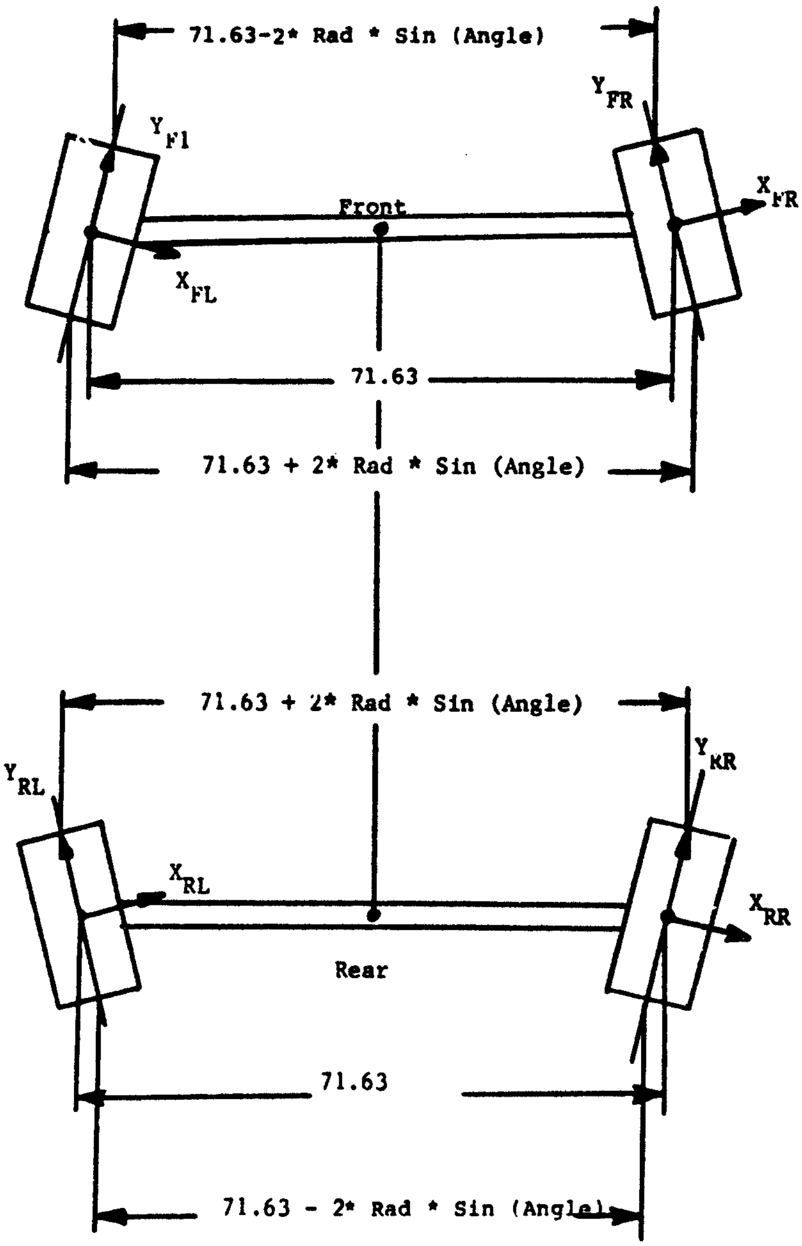


Figure 5-8. Static Toe Angle Calculations

Table 5-12. Spring Usage

Vehicle	Model	Front Springs	Rear Springs
Cargo/Troop Carrier	M998	5579473	5579471
Armament Carrier	M1043	5579473	5579471
TOW W/C	M966	5579473	5579471
S250 Shelter Carrier	M1037	5579473	5597913
Maxi-Ambulance	M997	5579473	5597913
Mini-Ambulance	M996	5579473	5597913
L119 8600 GVW	M998	5594500	5594499
L119 9300 GVW	M998	5594500	5594996

attachment point for the heavy duty rear suspension unit is different from the chassis attachment point for the standard rear suspension units. The front suspension units have spring (5579473). Table 5-13 shows the spring characteristics.

5.3.7. Shock Absorbers. Shock absorbers are used in each suspension unit to provide dissipative forces. The shock absorbers are placed inside the spring elements and are connected between the lower control arms and the chassis frame. The shock absorber attachment points are shown in Figures 5-2 through 5-7. The HMMWV M1037 S-250 Shelter Carrier has heavy duty suspension units in the rear and uses shock absorbers 12340072 (5590597). The front suspension units are equipped with shock absorbers 12340071 (5590327).

The shock absorbers provide a damping force proportional to the relative velocity between the shock piston rod and the shock piston cylinder. The HMMWV shock absorber has three ranges of operation -a midstroke region and two hydraulic bump stop regions. Hydraulic bump stops are built into the shocks near the end of travel in each direction to increase the damping force before metal-to-metal contact occurs.

Shock absorber hydraulic bump stops are engaged at:

COMPRESSED LENGTH AT START OF ENGAGEMENT = 13.76 INCHES
EXTENDED LENGTH AT START OF ENGAGEMENT = 15.85 INCHES

Shock absorber metal-to-metal contact occurs at:

COMPRESSED LENGTH AT METAL TO METAL CONTACT = 12.76 INCHES
EXTENDED LENGTH AT METAL TO METAL CONTACT = 16.48 INCHES

The tolerance on the above dimensions is plus or minus one-eigth of an inch.

When metal-to-metal contact occurs a large force proportional to the metal-to-metal penetration is generated in the shock. Metal-to-metal penetration represents the deflection and the buckling of the internal shock absorber components. The metal-to-metal contact force was calculated using a linear stiffness value of 150,000 lbs per inch of penetration. There are no data or test results to support this stiffness value but this value was assumed and based upon the material yield limits.

The hydraulic bump stops have no stiffness characteristics. If the shock is within the bump stop region and at rest (0 velocity), then there are no forces generated in the shock. The only time the hock can exert a force is when there is a relative velocity or when metal-to-metal contact occurs. When the bump stop region is encountered the shock's effective piston area is increased. As a result of increasing the effective area, the shock damping forces are also increased. Test Report L013497 produced by Monroe Auto Equipment for AM General gives the damping forces

Table 5-13. Spring Characteristics

Spring Number	5579471	5579473	5597913	5594500	5594499	5594996
Location	Rear Normal	Front	Rear Heavy Duty	Front	Rear	Rear
Nominal Spring Rate (lbs/inch)	1,728	954	2,108	954	2,108	2,520
Spring Rate Tolerance (lbs/inch)	69.1	38.2	84.3			
Nominal Design Load (lbs)	4,726	3,491	6,388	2,982	5,705	6,515
Design Load Tolerance (lbs)	94.5	69.8	127.75			
Height at Design Load (inches)	9.70	9.70	12.00	9.70	12.00	12.00
Free Height (inches)	12.43	13.36	15.03	12.93	14.71	14.59
Wire Diameter (inches)	1.044	0.904	1.173	0.904	1.173	1.219
Solid Height	6.50	6.03	8.44			

at three different frequencies throughout each shock absorber region. A copy of the Monroe Test Report L013497 is included in Appendix A.

The shock absorber tests described in Test Report L013497 cycled the shock in each region with a 1.5-inch stroke using a haversine signal input. The haversine signal function used in the test is given by the function:

$$f(x) = 1.50*1/2*(1-\cos(wt))$$

$$f'(x) = 0.75*w*\sin(wt)$$

The maximum velocity obtained by the shock during the test is (0.75*w).

Figure 5-9 shows the resulting force versus velocity curves for the front shock absorber, 12340071, at 30-, 85-, and 170-cycles-per-minute frequency in each operating region. Figure 5-10 shows the resulting force versus velocity curves for the heavy duty rear shock absorber, 12340072, at 30-, 85-, and 170-cycles-per-minute frequency in each operating region. The force values plotted on the curves are the average values obtained during the test and have a tolerance of plus or minus 25%.

The DADS Translational Spring Damper Acutuator (TSDA) element was used to model the shock absorber. Since the shock absorber has several operating regions and different damping coefficients in each region, the DADS code had to be expanded to perform the correct calculations for each operating region. Subroutine FRC10.FOR was modified to call USER_TSDA.FOR. Shock calculations were performed in the USER_TSDA.FOR routine. The logic of USER_TSDA.FOR routine requires that the spring and shock input data in the *.FM3 file be entered in a specified order. The four springs must be defined in TSDA elements 1 through 4. The front shock absorbers must be defined in TSDA elements 5 and 6 while the rear shock absorbers must be defined in TSDA elements 7 and 8.

The function routine called CUBIC1.FOR was written to provide a smooth transition, within the tolerance of the shock absorber, between the three operating regions. The discontinuities between the operating regions severely slow down the numerical integration algorithm by forcing it to take smaller step sizes at the discontinuity. The use of CUBIC1 speeds up the simulation.

The properties of the CUBIC1 function are as follows:

$$f(0) = 0.0$$
$$f(1) = 1.0$$
$$f'(0) = f'(1) = 0.0$$

The CUBIC1 function used to model the transitions between the different operating reigions is derived below.

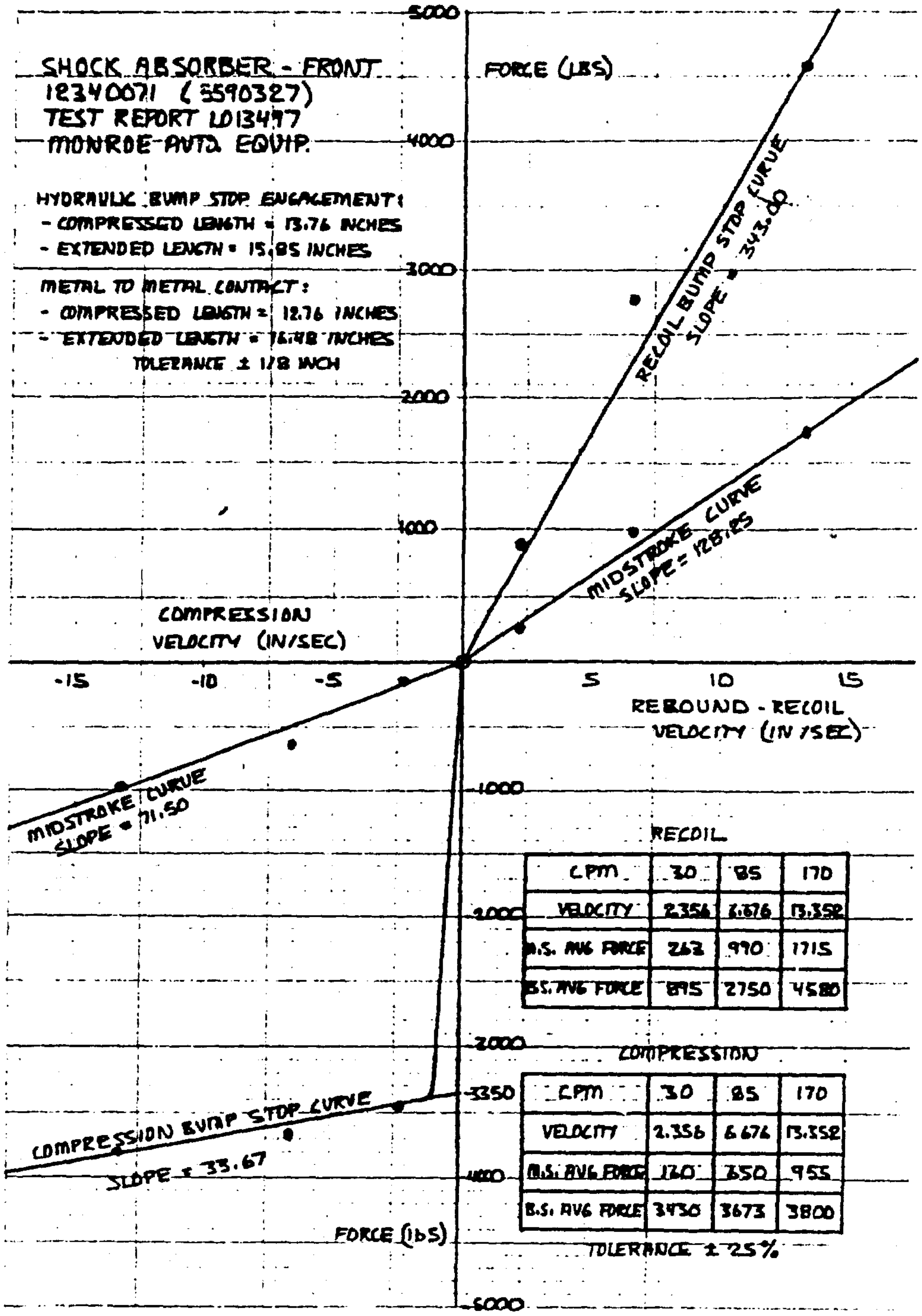
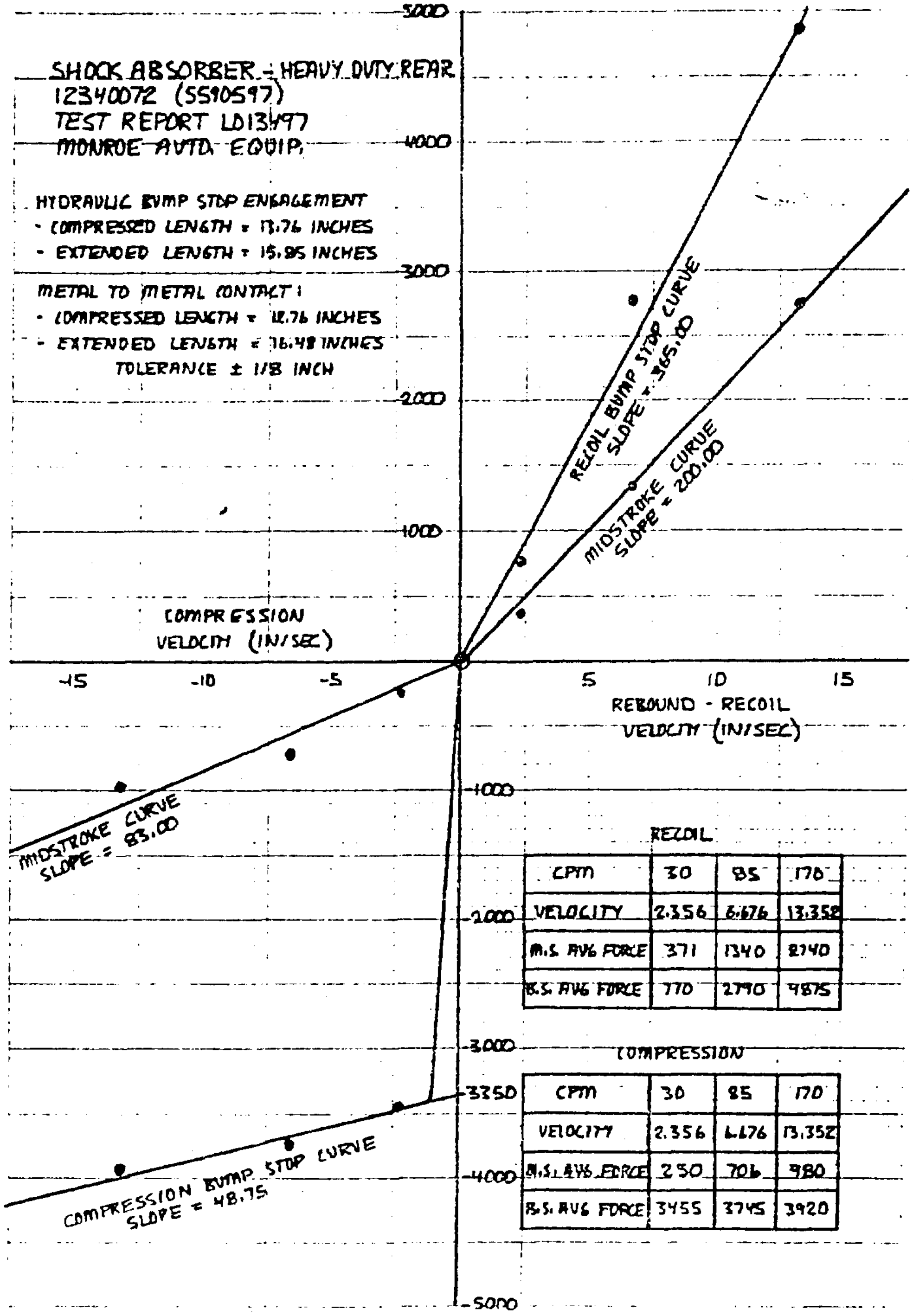


Figure 5.9. Front Shock Absorber Curve



CPM	30	85	170
VELOCITY	2.356	6.676	13.352
M.S. AVG FORCE	371	1340	2740
B.S. AVG FORCE	770	2790	4875

CPM	30	85	170
VELOCITY	2.356	6.676	13.352
M.S. AVG FORCE	250	706	980
B.S. AVG FORCE	3455	3745	3920

Figure 5.10. Heavy Duty Rear Shock Absorber Curve

$$f(x) = a(x^{3}) + b(x^{2}) + cx + d$$
$$f'(x) = 3a(x^{2}) + 2bx + c$$

$$f(0) = 0 = d$$
$$f(1) = a + b + c = 1$$

$$f'(0) = 0 = c$$
$$f'(1) = 3a + 2b = 0$$

$$b = 3$$
$$a = -2$$

The resulting function is shown below.

CUBIC1: $f(x) = -2(x^{3}) + 3(x^{2})$ for $0 <= x <= 1$
$f'(x) = -6(x^{2}) + 6(x)$ for $0 <= x <= 1$

5.3.8. Friction. Coulomb friction in the suspension units plays a role in the suspension forces and was included in the HMMWV model. The friction forces for each suspension unit were assumed to act along the shock absorber. These forces were calculated in subroutine USER_TSDA.FOR and added to the system in the TSDA element describing each shock absorber. The University of Michigan Transportation Research Institute (UMTRI) conducted a parameter measurement study of a HMMWV vehicle and found that the coulomb friction in the front suspension unit is 106 lbs and the coulomb friction in the rear suspension unit is 112 lbs. Because the friction forces act in different directions depending on the direction of motion, coulomb friction was modeled using a cubic function. A copy of the UMTRI test results is given in Appendix B.

The function routine CUBIC.FOR was written to model coulomb friction. This type of force, like other frictional forces, is not linear and is independent of the contact area and the magnitude of the relative velocity as long as motion exists.

The properties of the CUBIC function are as follows:

$$f(-1) = -1.0$$
$$f(0) = 0.0$$
$$f(1) = 1.0$$
$$f'(-1) = f'(1) = 0.0$$

The CUBIC routine provides a smooth transition between the range f(-1) and f(1). Discontinuities severely slow down the numerical integration algorithm by forcing it to take smaller step sizes at the discontinuity. The use of CUBIC speeds up the simulation by eliminating the discontinuity associated with frictional-type forces.

The CUBIC routine used for modeling coulomb friction is derived below.

$$f(x) = a(x^{3}) + b(x^{2}) + cx + d$$

$$f'(x) = 3a(x^{2}) + 2bx + c$$

$$f(0) = 0 = d$$

$$f(1) = a + b + c = 1$$
$$f(-1) = -a + b - c = -1$$

$$2b = 0$$

$$f'(1) = 3a + c = 0$$
$$f'(-1) = 3a + c = 0$$

$$6a + 2c = 0$$

$$a = -1/2$$
$$c = 3/2$$

CUBIC: $f(x) = -1/2(x^{3}) + 3/2(x)$ for $-1 <= x <= 1$
$f'(x) = -3/2(x^{2}) + 3/2$ for $-1 <= x <= 1$

5.3.9. Auxiliary Roll Stiffness. A roll stabilization bar is connected between the two front lower control arms. The rear suspension units are not equipped with a roll stabilization bar. A rotation of the vehicle sprung mass about the fore-aft axis with respect to a transverse axis joining the lower control arms at their center of gravity is defined as suspension roll. Given a suspension roll angle, an auxiliary roll stabilization force is generated by the roll stabilization bar at each lower control arm.

Parameter measurements of the HMMWV conducted by UMTRI determined the vertical roll stiffness. At a nominal wheel load of 1,500 pounds the vertical stiffness at the wheel was measured with both the roll stabilization bar active and with the roll stabilization bar disconnected. Comparing the two vertical stiffness, UMTRI determined that the auxiliary roll stiffness at the wheel was 54 pounds per inch. A copy of the UMTRI test results is given in Appendix B.

The roll stabilization bar calculations are performed in the DADS TACOM-TIRE force element subroutine FRC36.FOR. The logic of FRC36.FOR routine requires that the chassis and front lower control arms input data in the *.FM3 file be entered in the order specified in Table 5-14.

Subroutine FRC36.FOR also requires that the Auxiliary roll stiffness dimensions be given as pounds of force per suspension roll in radians at the lower control arm center of gravity.

5.3.10. Tires. For this analysis Goodyear bias-type tires 36X12.50 LT Wrangler II were used. Tire pressures of 20 pounds per square inch (psi) on the front and 30 psi on the rear are maintained on the HMMWV 1037 S250 Shelter Carrier Vehicle. Goodyear Tire Company provided the Tire Normal Force Displacement Curve, the Lateral Force versus Slip Angle and

Table 5-14. Required Order of Body Input Data

Body Element Number	Element Name
1	Chassis
2	Lower Front Left Control Arm
3	Lower Front Right Control Arm

Vertical Load Curve, and the Aligning Torque versus Slip Angle and Vertical Load Curve at several operating pressures. All of this data are included in Appendix C. The vertical load curves at 20 psi and 30 psi were used in this analysis. The lateral force and aligning torque curves were not used in this analysis because the data was only measured up to 6 degrees of tire slip. For this analysis tire slip angles may reach 12 degrees or more and it is not valid to extrapolate the data to that degree.

Lateral tire force characteristics were also measured by UMTRI and are given in Appendix B. The lateral force data measured by UMTRI are valid up to 16 degrees of tire slip. For this reason the UMTRI lateral force data were used for this analysis. Unfortunately UMTRI did not measure tire aligning torque characteristics, therefore the aligning torque data was set to zero for this analysis.

Longitudinal forces for the turning wheel are based upon longitudinal tire slip and vertical normal force. When the tire is rolling more rapidly or less rapidly than the angular spin velocity then a longitudinal slip is generated. Tire slip means that this tire is being distorted and does not necessarily imply that sliding exists between the tire tread rubber and the roadway. The longitudinal force coefficient curve relating the ratio between longitudinal force and vertical normal force to longitudinal slip is shown in Figure 11.

The DADS TACOM-TIRE element, module 36, was used to model the tire. The tire force calculations are performed in the subroutine TIREF.FOR. These forces were then transferred to FRC36.FOR where they were appended to their respective body elements.

5.3.11. Run-Flat Device. Run-flat devices are inserted inside each wheel to allow operation of the vehicle in case of a flat tire. The run-flat system consists of a two-piece, bolt-on die cast magnesium inner tire support. The surface acting as a support during run-flat conditions is 3.5 inches wide. The run-flat device radius is approximately 12.50 inches. The free radius of the tire is 18.15 inches. Assuming that the tire carcass is 1 inch thick, a tire deflection of more than 4.65 inches would create contact between the run-flat insert device, the tire carcass, and the road. When contact occurs the run-flat device would generate forces proportional to the penetration into the run-flat device to help support the vehicle.

The stiffness of the run-flat device was assumed to be 10,000 pounds per inch of penetration and the dissipative forces associated with the device were assumed to be zero. The run-flat calculations are performed in subroutine TIREF.FOR.

5.3.12. Ball Joints. To determine if the ball joint stud made an interference contact with the ball joint housing, the relative angle between the ball joint housing and the ball joint stud was calculated.

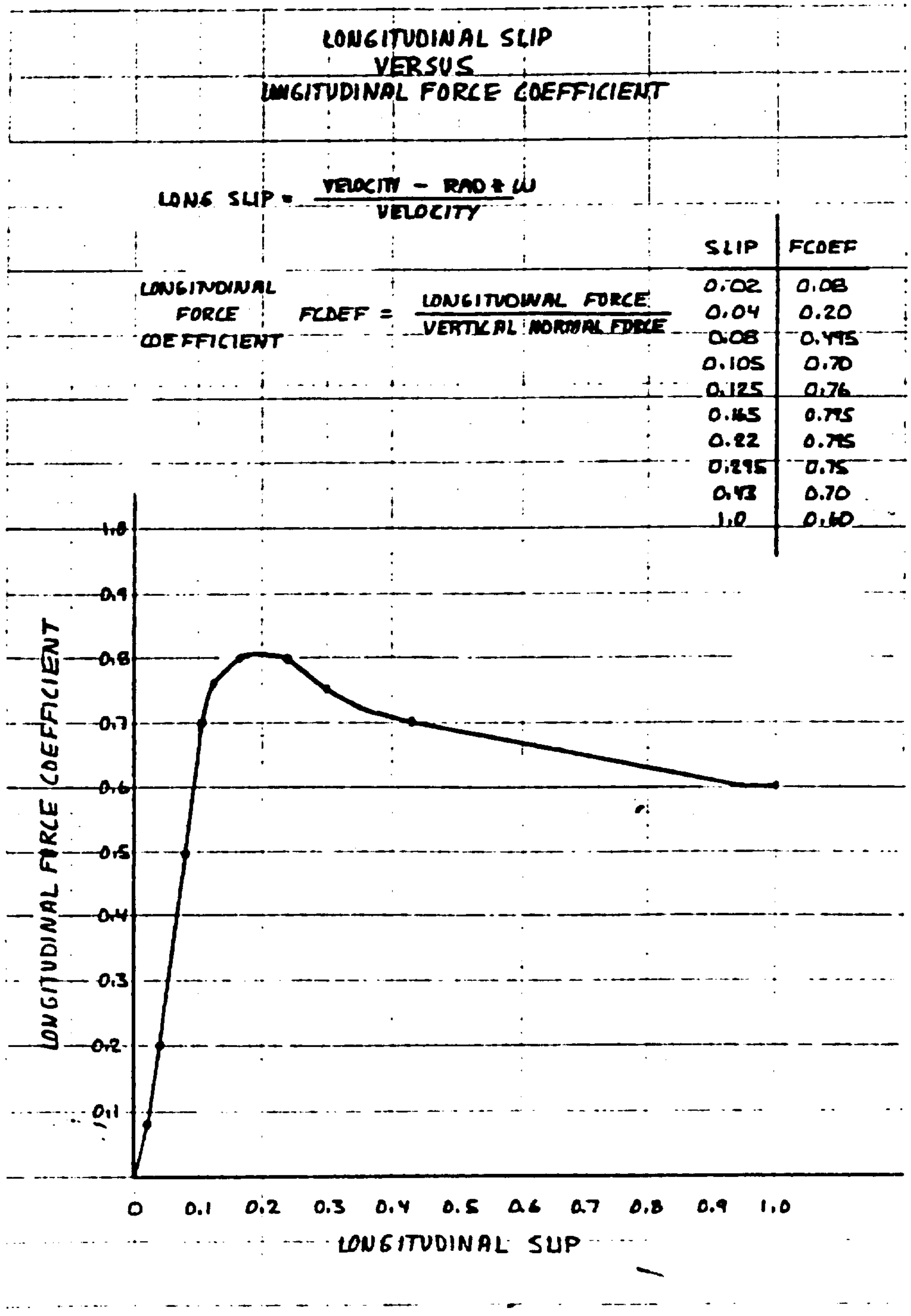


Figure 5-11. Longitudinal Slip Versus Longitudinal Force Coefficient Curve

The maximum allowable angle between the stud and housing for the upper and lower joints is given in Table 5-15.

The DADS spherical joint element was used to calculate the relative angle between the stud and the housing. A unit joint axis on the control arm was defined to be perpendicular to the ball joint housing. With the suspension unit in the design position, this unit joint axis represents a global rotation of 12.00 degrees and a rotation of 3.00 degrees. A unit joint axis on the ball joint stud or wheel hub assembly was defined along the kingpin axis. Since both joint axis are unit vectors, taking the dot product between the housing joint axis and the stud joint axis will determine the relative angle. The DADS code was expanded to calculate the relative angle. The subroutine MM15.FOR was modified to call FRC15.FOR. Subroutine FRC15.FOR uses the joint axis to calculate the relative joint angle.

If the forces in the spherical joints are calculated in the joint coordinate system described above, then the forces along the unit joint axis on the ball joint stud would represent tensile or compression loading. Shear force can be calculated from the force components perpendicular to the ball joint stud axis.

5.4. Steering

5.4.1. Steering Description. The HMMWV is equipped with power assisted steering. The power steering assembly is located at the left-hand side. The power steering pump is a Saginaw Steering Gear model 125. The power steering pump is a belt driven vane-type pump with a rated capacity of 2.6 GPM at 1,500 rpm. The steering gear make and model is Saginaw Steering Gear model 708. The steering gear is a recirculating ball, worm, and nut device with a 13/16:1 ratio. Figures 5-12 through 5-14 show the steering geometry and dimensions.

Steering limits are determined by steering stops located on the wheel hub assembly and the lower control arm. Steering stops are adjusted to limit steering at 36.00 degrees for the inside steered wheel. Figure 5-15, taken from TM 9-2320-280-20, pages 6-36 and 6-37, shows the steering stop angle.

For this analysis the steering input command was constantly equal to zero throughout the simulation.

5.5. Terrain

5.5.1. Course Profile Description. Vehicle tests at NATC were conducted over a manmade test course with seven obstacles. A survey of the test course profile is given in Appendix D. This NATC course profile description was used for this HMMWV ball joint analysis.

5.6. Dynamic Analysis

Table 5-15. Maximum Allowable Ball Joint Angle

Ball Joint	Maximum Allowable Angle
Lower	19.5 Degrees
Upper	30.0 Degrees

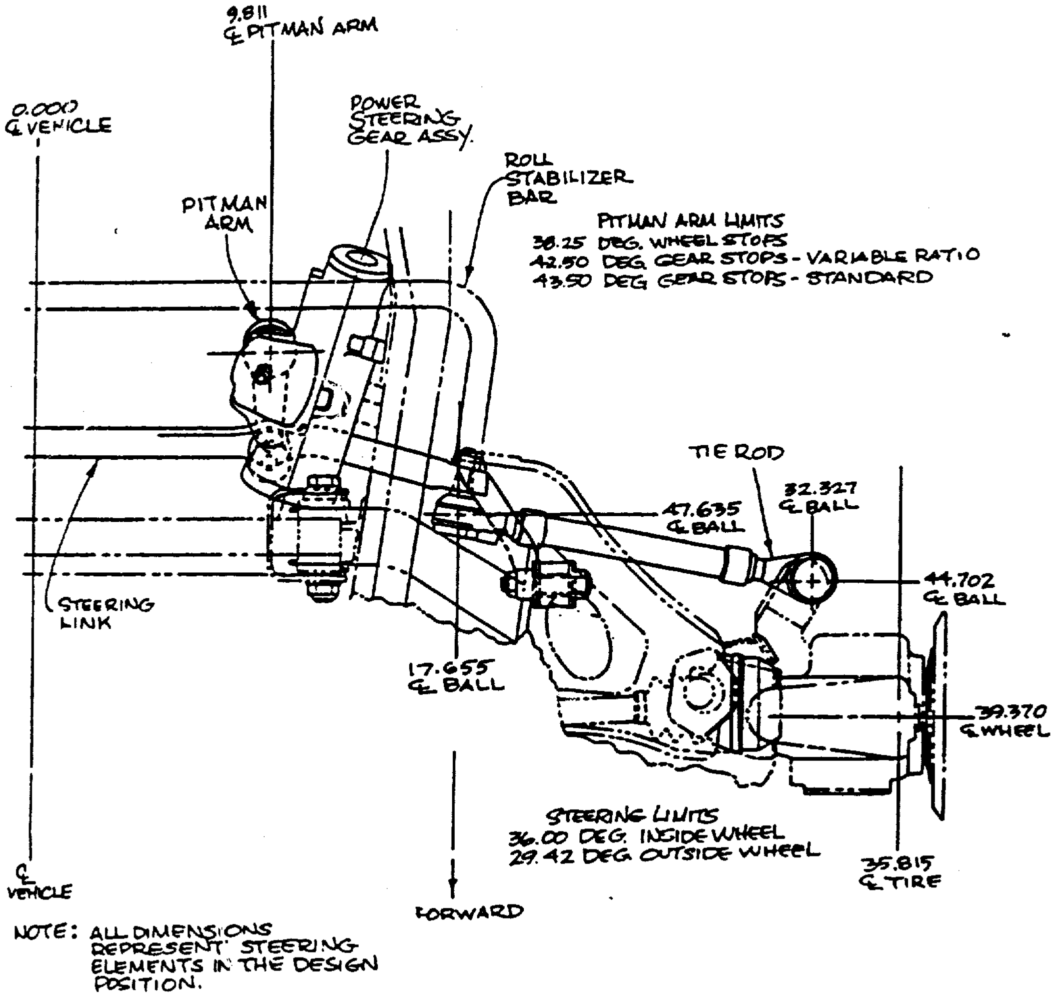


Figure 5-12. Steering Left Side, Top View

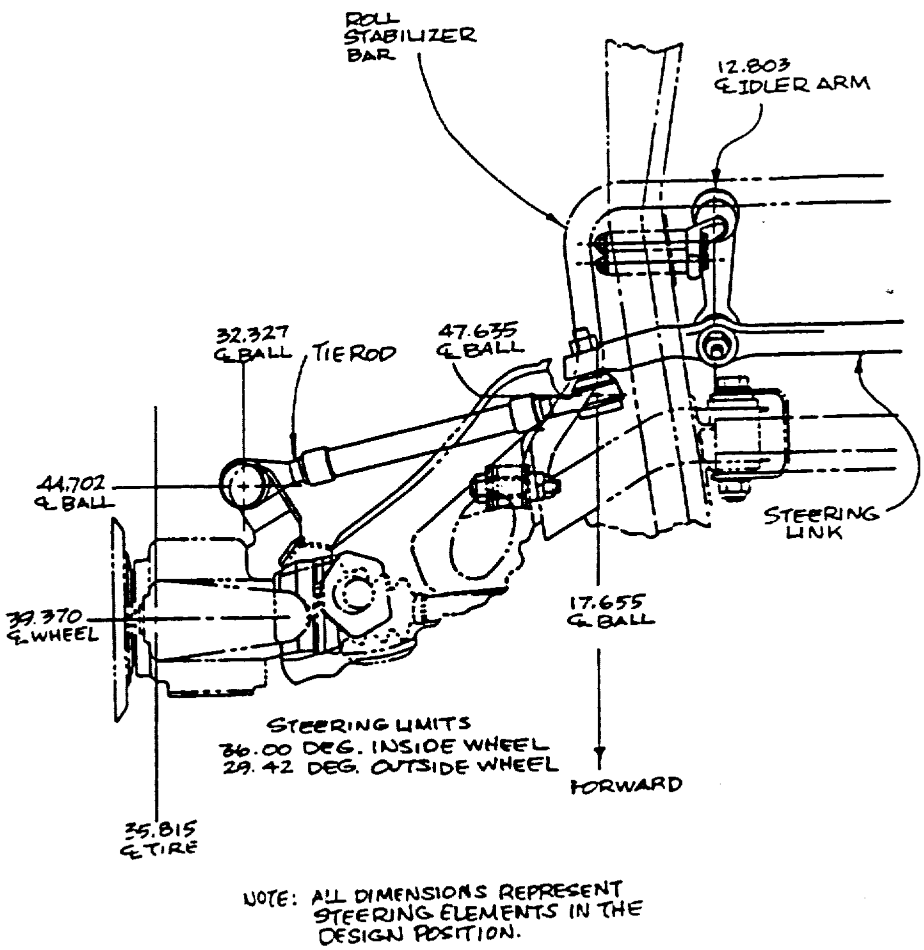


Figure 5-13. Steering Right Side, Top View

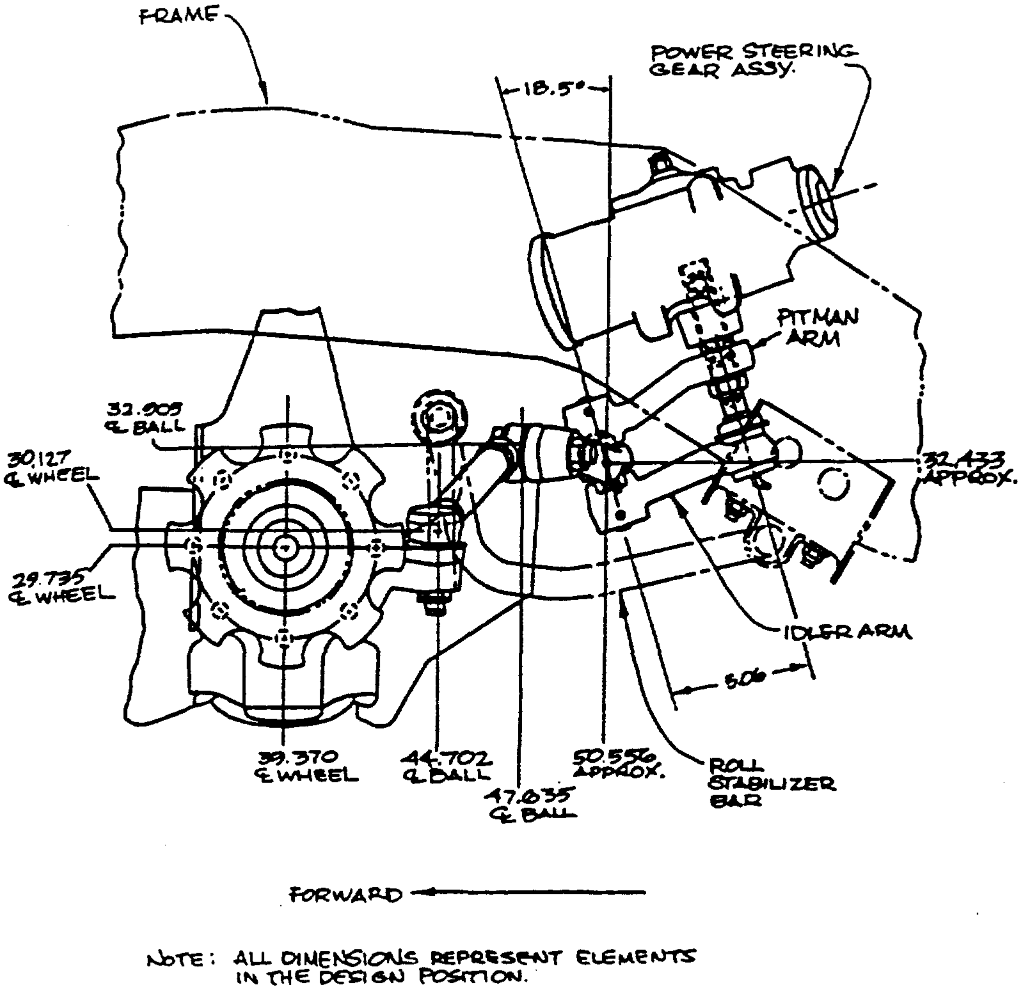


Figure 5-14. Steering, Left Side View

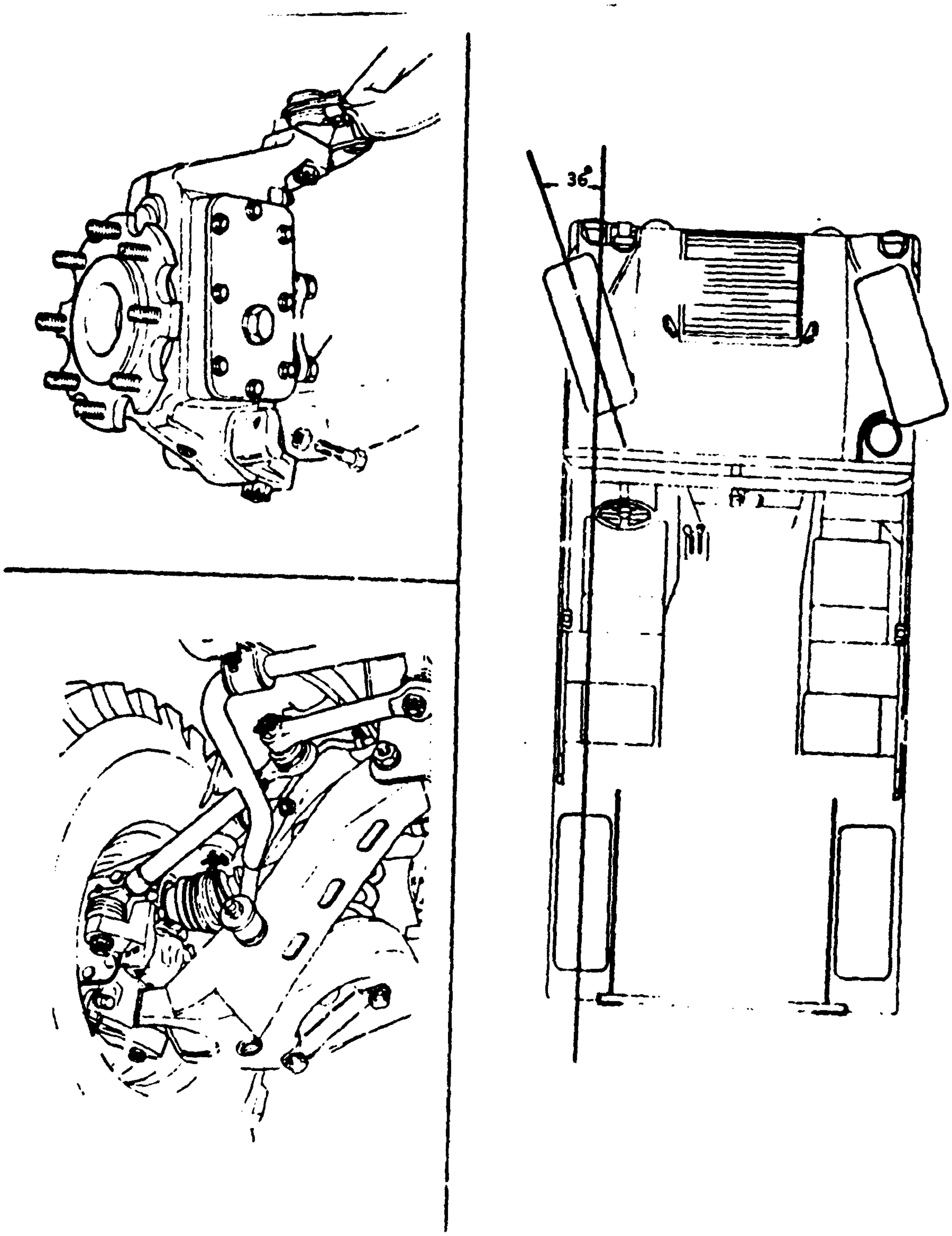


Figure 5-15. Steering Stops

5.6.1. HMMWV Model. The purpose of this dynamic analysis is to simulate the vehicle's dynamic response from negotiating the NATC course. The initial vehicle speed was 15 mph for this analysis, the same as the actual speed employed at the vehicle tests conducted at NATC. During the simulation there was no simulated driver responce to braking, acceleration, or steering.

The analysis of the HMMWV employed the DADS methodology. The computer program builds a mathematical model of the system from a set of data input and calculates the position, velocity, and acceleration of various parts of the vehicle as well as the forces that act in the vehicle.

DADS contains a large library of mechanical elements that can be used to build a vehicle model. These elements include bodies, joints and other constraints, and force-and-torque producing elements. The HMMWV vehicle model was created using the three-dimensional version. All vehicle input data were described relative to a global reference frame located on the ground.

The coordinate reference frames used in this analysis are shown in Table 5-16.

The DADS elements listed in Table 5-17 were used to describe the HMMWV vehicle. A complete list of all the vehicle data can be found in the *.VB3 verbatim file and the *.INP user input data file listed in Appendix E. The data files are placed in the directory [AARDEMA.DADS3D.HMMWV.1037.HIGHCG.NATC]. To run the program in batch mode, execute command file *.SBM which will submit the job. To run the program interactively, execute the command file *.COM.

5.6.2. Program Enhancements. Several additions and modifications were made to the DADS code to more accurately model the vehicle characteristics and to provide easy access to output data. Table 5-18 lists the subroutines that were added or modified and a brief description of their purpose.

The source code additions and modifications are placed in the directory [AARDEMA.DADS3D.HMMWV.SOURCE] on the VAX8800 computer. All user common blocks are placed in the directory [AARDEMA.DADS3D.HMMWV.COMMON]. Command file COMP.COM was used to compile each subroutine. All object code are placed in the directory [AARDEMA.DADS3D.HMMWV.OBJECT]. The modified subroutines are then replaced in the object code libraries ANALYSIS.OLB, MOD3D.OLB, and USER3D.OLB by the command file LIB_REPLACE.COM. Command file LINK_DADS3D_HMMWV.COM is used to link all the subroutines and create an executable code. The executable code and mapping files are placed in the directory [AARDEMA.DADS3D.HMMWV.EXE].

5.6.3. Post Processing. The DADS post processor program provides a means of plotting and writing the simulation results. However, not all of the necessary information is available when user-written subroutines are implemented. For this reason an array named UPLOT was implemented

Table 5-16. Coordinate Reference Frames

Axis	Description
X - Axis	Right Side
Y - Axis	Forward
Z - Axis	Vertical

Table 5-17. DADS Elements

DADS ELEMENT	ELEMENT NAME	DESCRIPTION
HEADER	HEADER	Comments
SYSTEM	SYSTEM.DATA	Simulation Parameters
DYNAMIC	DYNAMIC.DATA	Simmulation Parameters
DISTANCE.CONSTRAINT	TIE-ROD.FL	Front Left Tie Rod
DISTRANCE.CONSTRAINT	TIE-ROD.FR	Front Right Tie Rod
DISTANCE.CONSTRAINT	RAD-ROD.RL	Rear Left Rad Rod
DISTANCE.CONSTRAINT	RAD-ROD.RR	Rear Right Rad Rod
TACOM-TIRE	TIRE.FL	Front Left Tire
TACOM-TIRE	TIRE.FR	Front Right Tire
TACOM-TIRE	TIRE.RL	Rear Left Tire
TACOM-TIRE	TIRE.RR	Rear Right Tire
TSDA	SPRING.FL	Front Left Spring
TSDA	SPRING.FR	Front Right Spring
TSDA	SPRING.RL	Rear Left Spring
TSDA	SPRING.RR	Rear Right Spring
TSDA	SHOCK.FL	Front Left Shock
TSDA	SHOCK.FR	Front Right Shock
TSDA	SHOCK.RL	Rear Left Shock
TSDA	SHOCK.RR	Rear Right Shock
REVOLUTE.JOINT	REV.LFL	Lower Front Left
REVOLUTE.JOINT	REV.LFR	Lower Front Right
REVOLUTE.JOINT	REV.LRL	Lower Rear Left
REVOLUTE.JOINT	REV.LRR	Lower Rear Right
REVOLUTE.JOINT	REV.UFL	Upper Front Left
REVOLUTE.JOINT	REV.UFR	Upper Front Right
REVOLUTE.JOINT	REV.URL	Upper Rear Left
REVOLUTE.JOINT	REV.URR	Upper Rear Right
REVOLUTE.JOINT	PITMAN.REV	Pitman Arm to Chassis
REV-SPHR	IDLER.ARM	Steering Link to Chassis
SPHERICAL	SPH.LFL	Lower Front Left Ball Joint
SPHERICAL	SPH.LFR	Lower Front Right Ball Joint
SPHERICAL	SPH.LRL	Lower Rear Left Ball Joint
SPHERICAL	SPH.LRR	Lower Rear Right Ball Joint
SPHERICAL	SPH.UFL	Upper Front Left Ball Joint
SPHERICAL	SPH.UFR	Upper Front Right Ball Joint
SPHERICAL	SPH.URL	Upper Rear Left Ball Joint
SPHERICAL	SPH.URR	Upper Rear Right Ball Joint
UNIVERSAL	PITMAN.UNIV	Steering Link to Pitman Arm

Table 5-17. DADS Elements (Continued)

DADS ELEMENT	ELEMENT NAME	DESCRIPTION
BODY	CHASSIS	Chassis
BODY	ARM.LFL	Lower Front Left
BODY	ARM.LFR	Lower Front Right
BODY	ARM.LRL	Lower Rear Left
BODY	ARM.LRR	Lower Rear Right
BODY	ARM.UFL	Upper Front Left
BODY	ARM.UFR	Upper Front Right
BODY	ARM.URL	Upper Rear Left
BODY	ARM.URR	Upper Rear Right
BODY	WHEEL.FL	Front Left
BODY	WHEEL.FR	Front Right
BODY	WHEEL.RL	Rear Left
BODY	WHEEL.RR	Rear Right
BODY	PITMAN.ARM	Steering Arm
BODY	STEERING.LINK	Steering Link
INITIAL CONDITION	INIT.CHASSIS.ORIEN	Chassis Orientation
INITIAL CONDITION	INIT.CHASSIS.X	Chassis X
INITIAL CONDITION	INIT.CHASSIS.Y	Chassis Y
INITIAL CONDITION	INIT.CHASSIS.Z	Chassis Z
INITIAL CONDITION	INIT.WHEEL.FL	Front Left Wheel Z
INITIAL CONDITION	INIT.WHEEL.FR	Front Right Wheel Z
INITIAL CONDITION	INIT.WHEEL.RL	Rear Left Wheel Z
INITIAL CONDITION	INIT.WHEEL.RR	Rear Right Wheel Z
DRIVER	DRIVER	Steering Command
CURVE	TIRE.COEF	Tire Longitudinal Slip Coefficient
CURVE	BIAS.TIRE.20PSI	Tire Vertical Force @ 20 psi
CURVE	BIAS.TIRE.30PSI	Tire Vertical Force @ 30 psi
CURVE	TRAJECTORY	Steering Trajectory

Table 5-18. Subroutines Modified or Added

SUBROUTINE	DESCRIPTION
ATB.FOR	Multiplies a 3X3 matrix "A" by a 3X3 matrix "B".
BLOCKD.FOR	Modified the size of the TIRE and ITIRE arrays for the TACOM tire model and set the record length for the input data.
CARPET.FOR	Calculates the lateral force and the aligning torque as a function of slip and normal force given in the tire carpet plot data.
CUBIC.FOR	Provides a smoothing function to model coulomb friction. See section 5.3.8 titled "Friction" for more information.
CUBIC1.FOR	Provides a smoothing function to model trans- itions between events. See section 5.3.7 titled "Shock Absorbers" for more informa- tion.
DADS.FOR	Added the TACOM-TIRE element to the DADS element library.
EXEUNT.FOR	Added the closing of the movie file *.MOV, the shared file *.SHR, the user input file *.INP, and the auxillary output file *.AUX.
FRC10.FOR	Added a call to the user written subroutine USER-TSDA.FOR to calculate shock forces. These forces, called UFORCE, were add to the total force in the TSDA element.
FRC15.FOR	Calculate the angle between the ball joint stud axis and the ball housing axis.
FRC36.FOR	Calculate tire dynamics and appends tire forces to the wheel bodies. Performs speed controller calculations and performs roll stabilization bar calculations.
IN36.FOR	Modified to read element number 36 which contains TACOM-TIRE data. Also added a call to subroutine USET.FOR to read in additional tire and terrain data.

Table 5-18. Subroutines Modified or Added (Continued)

SUBROUTINE	DESCRIPTION
IN49.FOR	Modified to get the number of driver differential equations used by the relative angle type driver. The number is stored in variable NDRVDE.
JNCTN.FOR	Added MM36 to the external call list and added the GOTO call for MM36.
MAINB.FOR	Added the opening and sharing of the movie file *.MOV, the shared file *.SHR, the user input file *.INP, and the auxillary user output file *.AUX.
MM03.FOR	Modified the call list to RPT03.FOR to include the user differential variable arrays UDE and DUDE.
MM15.FOR	Added the call to FRC15.FOR.
MM36.FOR	This subroutine is called by JNCTN for TACOM tire information. It call IN36 to read input data, MOVE36 to set initial conditions for the user differential equation, FRC36 to calculate tire dynamics and tire forces, and RPT03 to report data to output file. The size of NY and NYTOT are increased for integrating the tire rotational accelertions and velocities.
MOVE36.FOR	Sets the initial conditions for the user differential equations.
RPT03.FOR	Added code to write out animation data to the movie file and the shared file.
RPT36.FOR	Reports TACOM-TIRE results to the output file *.OUT.
SURF.FOR	Calculates the elevation of a point in a grid pattern which describes the terrain surface.
TIREF.FOR	Calculates tire forces for the TACOM tire model.
USER_TSDA.FOR	Calculates shock absorber forces.
USET.FOR	Reads in additional data from the user input file *.INP.

into the user-written subroutines to store the required user information. At each report interval the contents of UPLOT are written to the user output file *.AUX.

After the simulation is successfully completed the additional user data can be extracted from the *.AUX file by executing the EXTRACT.EXE file located in the directory [AARDEMA.DADS3D.HMMWV.EXE]. This data can be plotted by using the DADS post processor.

Shear forces within each ball joint are obtained by writing the joint perpendicular force components to an output file using the DADS post processor and then using the program SHEAR.EXE located in the directory [AARDEMA.DADS3D.HMMMWV.EXE] to calculate the shear force. A plot of the shear forces can be made using the DADS post processor.

The commands for extracting the user data from the UPLOT arrays are contained in the command file EXTRACT.COM. By executing this command file the data will be stored in the files *.DAT and can be plotted using the EXC command in the DADS post processor.

Many of the commands for plotting vehicle data and user data have been automated. By executing the command file PLOT.COM at a Tektronix terminal with a hard copy machine, the plots will automatically be created.

5.6.4. Dynamic Results. The following simulation results are for the HMMWV negotiating the NATC course at 15 mph.

Figures 5-16 through 5-18 show the chassis center of gravity vertical position, velocity, and acceleration. The chassis position data have a vertical offset of 13.38 inches because the ground elevation, as defined by the original vehicle layout drawings, is equal to 13.38 inches. This is clearly shown in Figures 5-2 through 5-7. The maximum vertical acceleration of 5.6 G's occurs when the rear wheels strike the ground after clearing the first obstacle.

Figures 5-19 through 5-21 show the chassis pitch angle, pitch velocity, and pitch acceleration. Positive pitch represents the vehicle front coming upwards. The maximum positive pitch acceleration occurs when the front wheels strike the ground after negotiating the first obstacle. The maximum negative pitch occurs while the front wheels are off the ground, after negotiating the second obstacle, and while at the same time the rear wheels are striking the ground after clearing the first obstacle. At this time the only contact the vehicle has with the ground is by the rear wheels.

Figures 5-22 through 5-24 show the chassis roll angle, roll velocity, and roll acceleration. Positive roll indicates that the vehicle is leaning on the right side. At the end of the simulation, where the course is flat, the vehicle settles out to a positive roll angle. This is a result of the CG being on the right side of the vehicle.

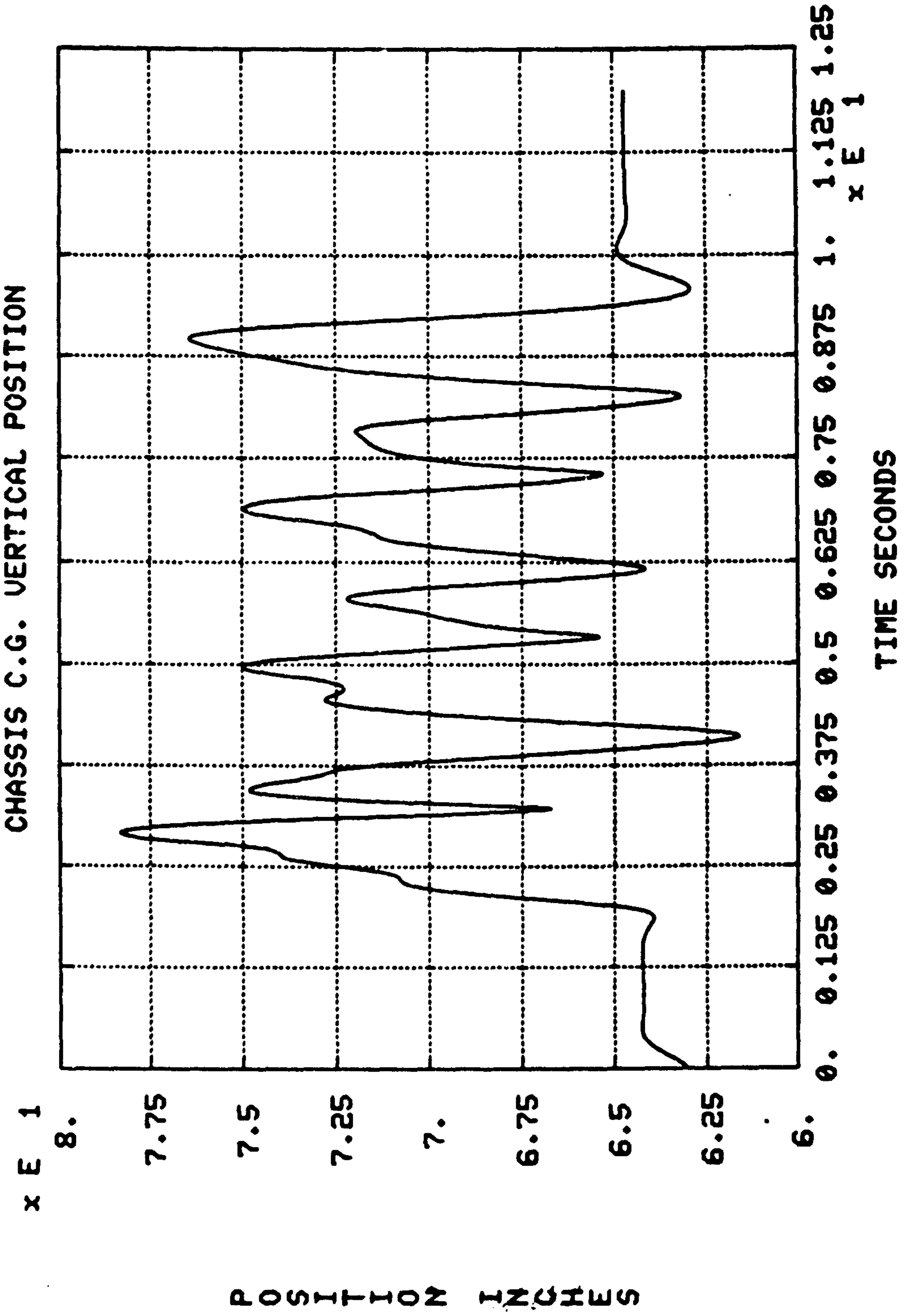


Figure 5-16. Chassis CG Vertical Position

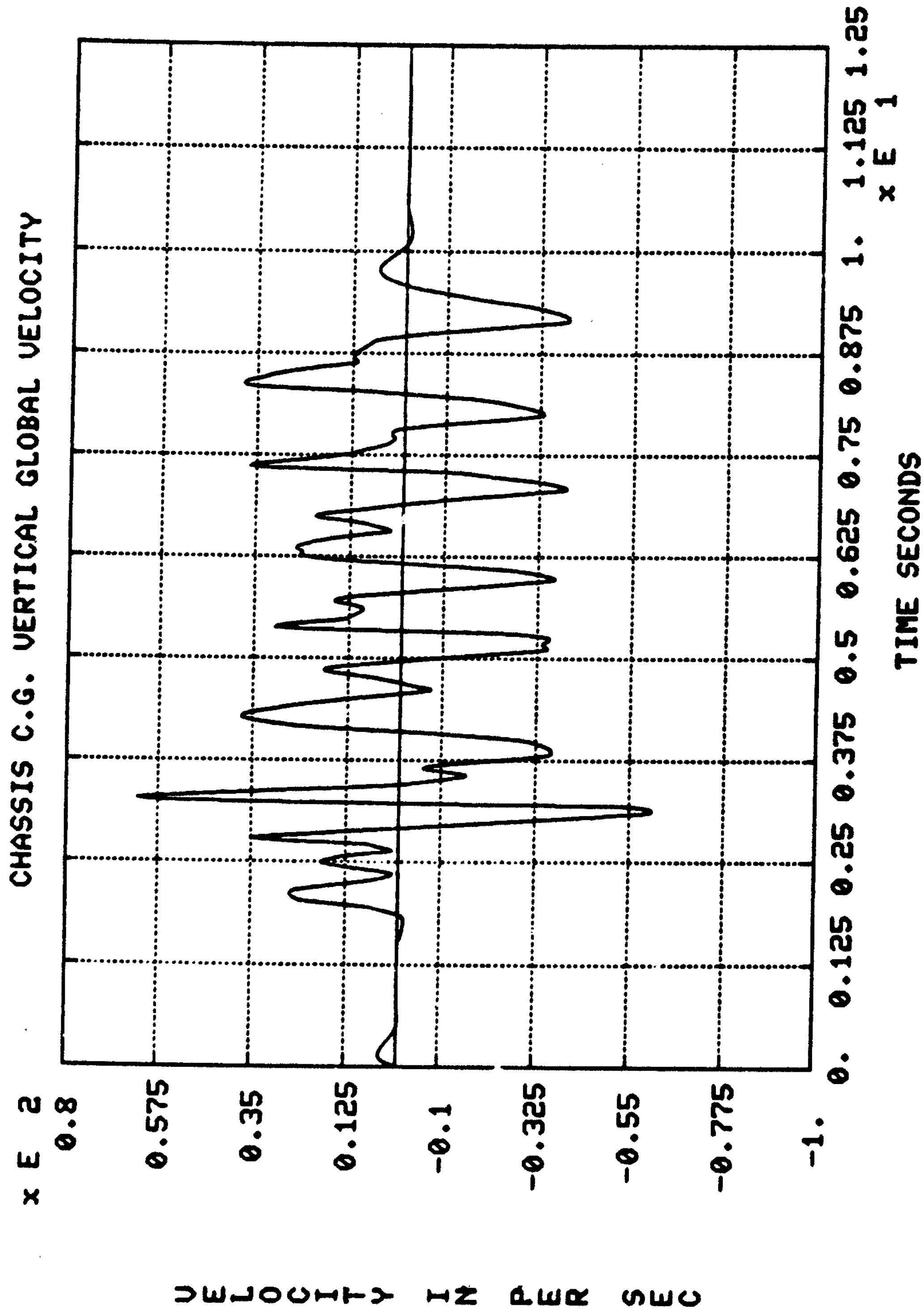


Figure 5-17. Chassis CG Vertical Global Velocity

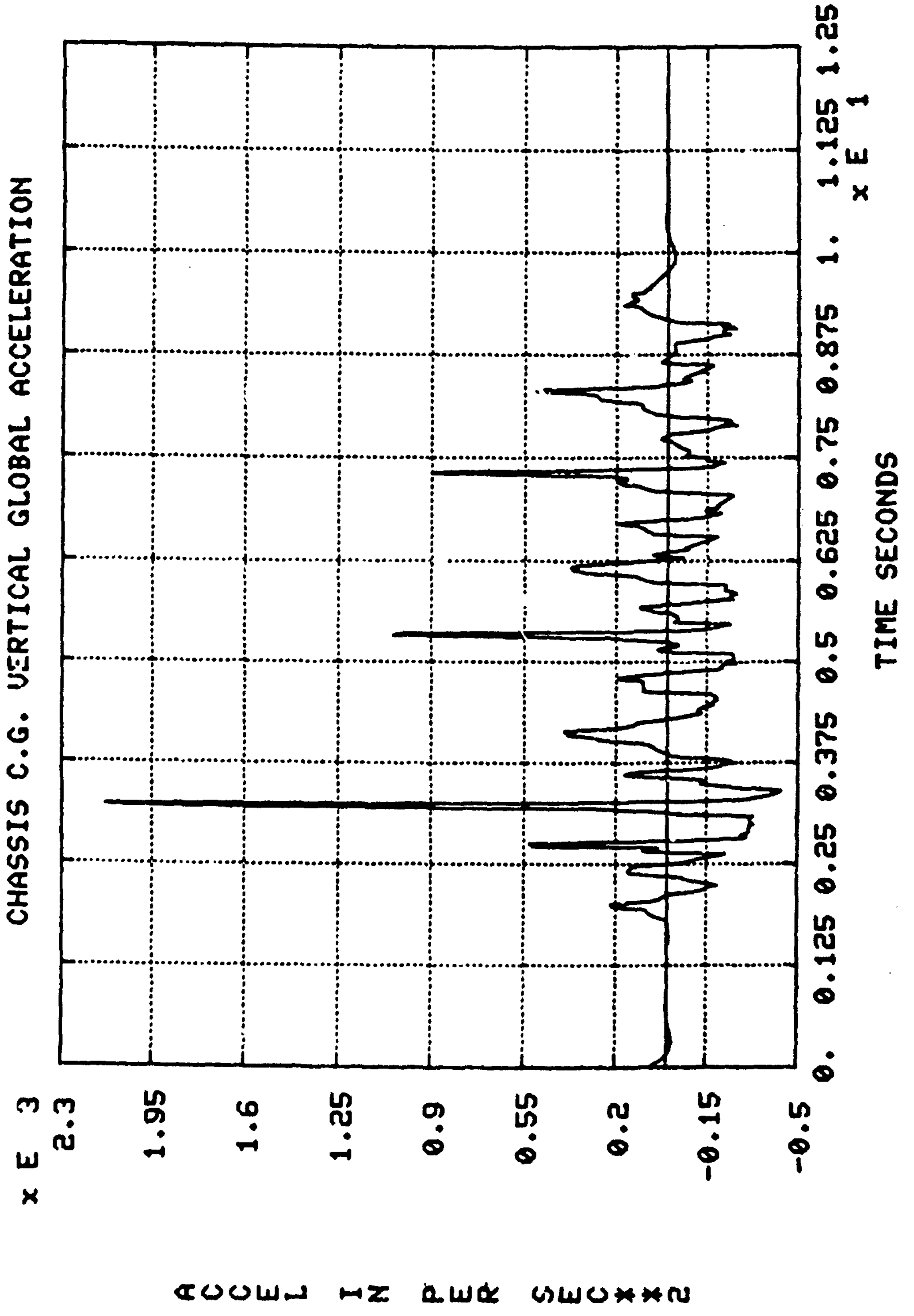


Figure 5-18. Chassis CG Vertical Global Acceleration

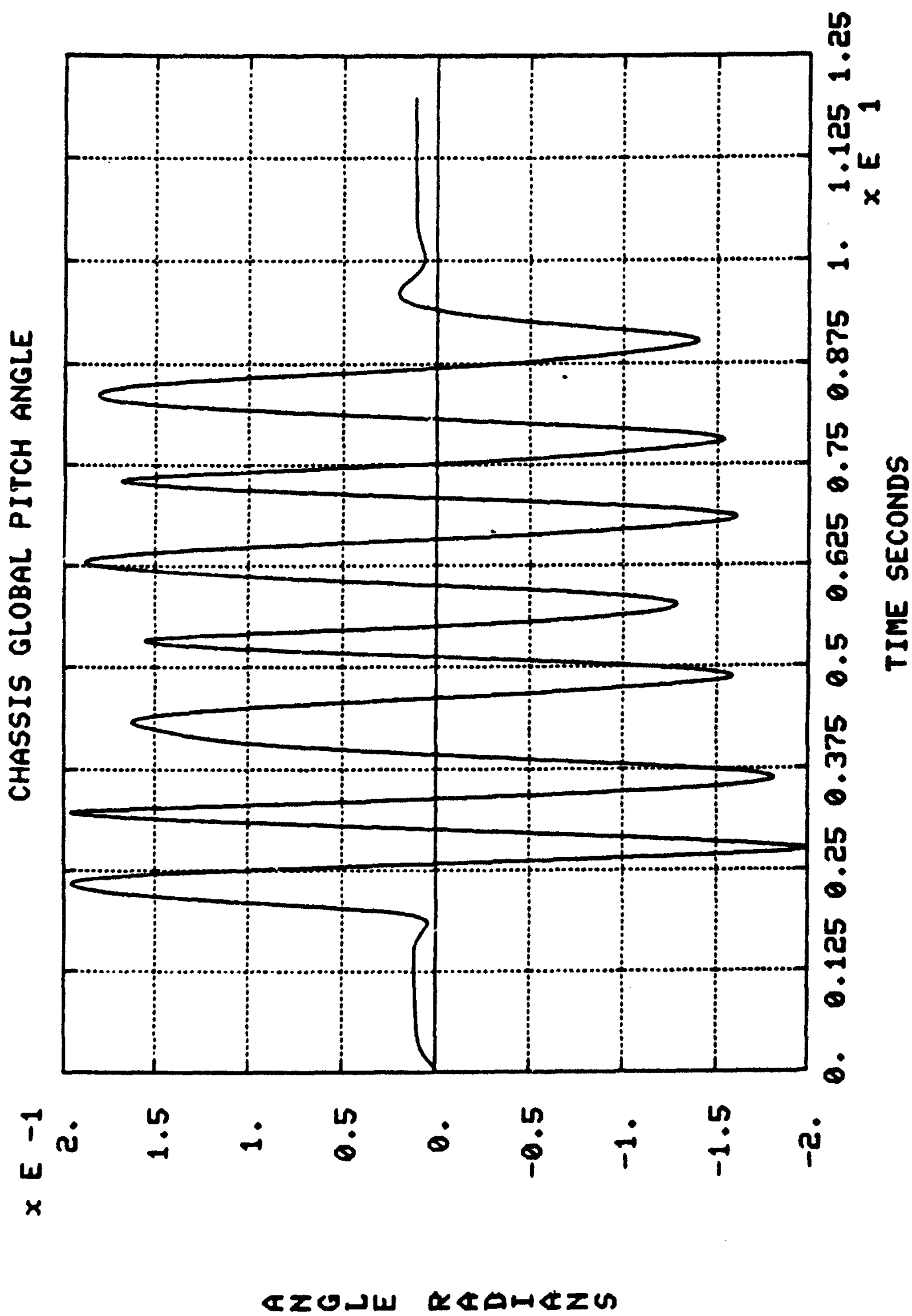


Figure 5-19. Chassis Global Pitch Angle

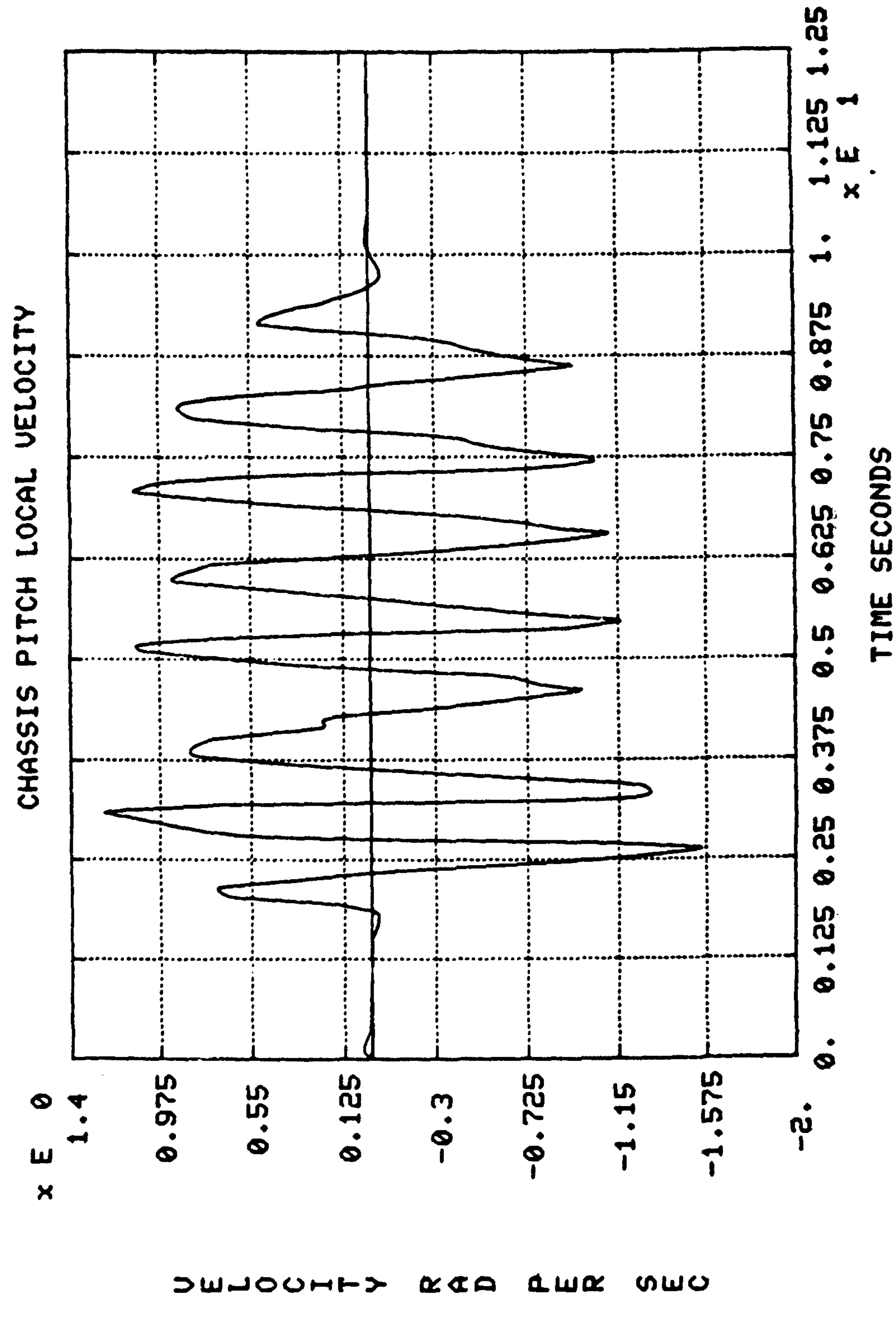


Figure 5-20. Chassis Pitch Local Velocity

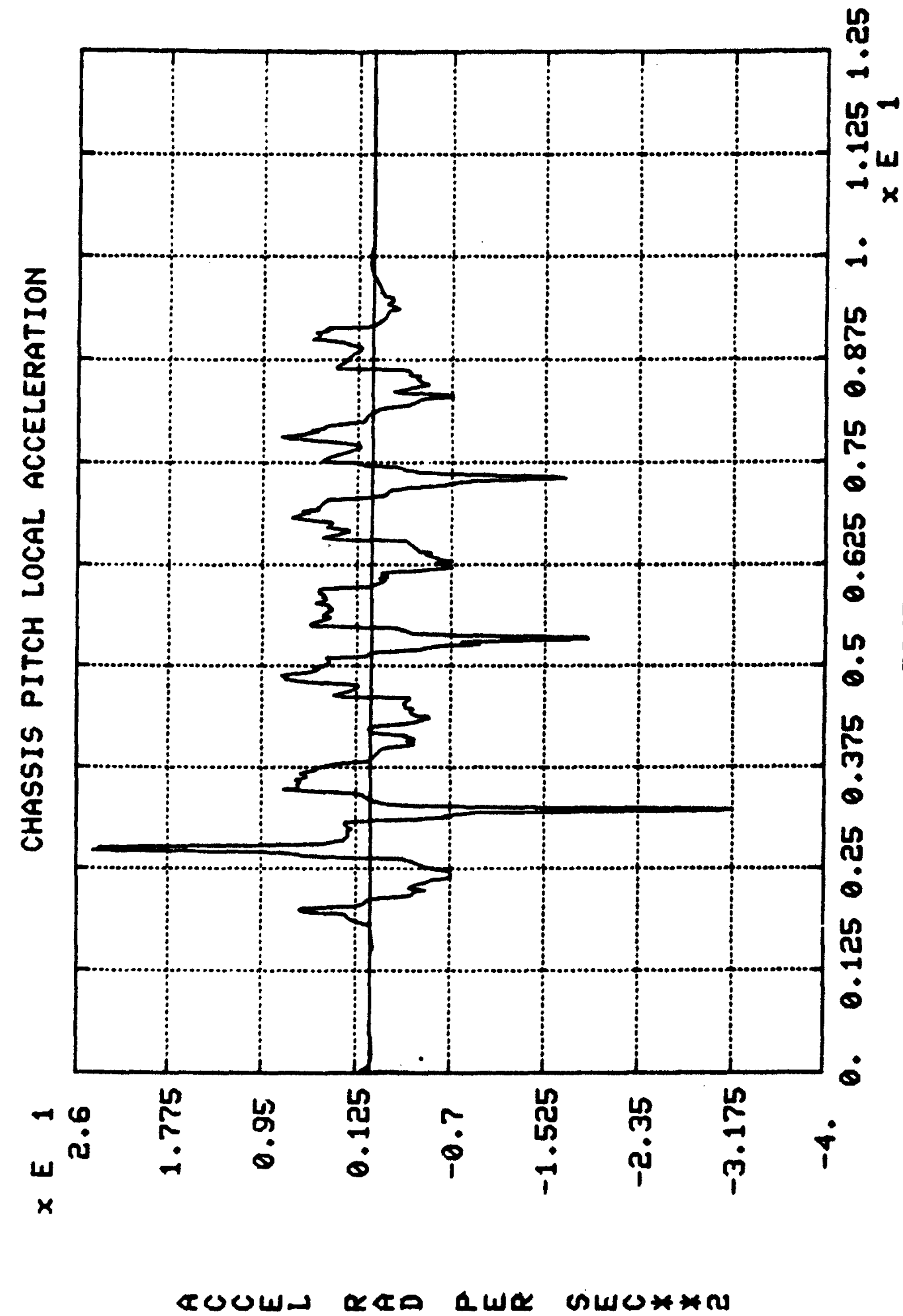


Figure 5-21. Chassis Pitch Local Acceleration

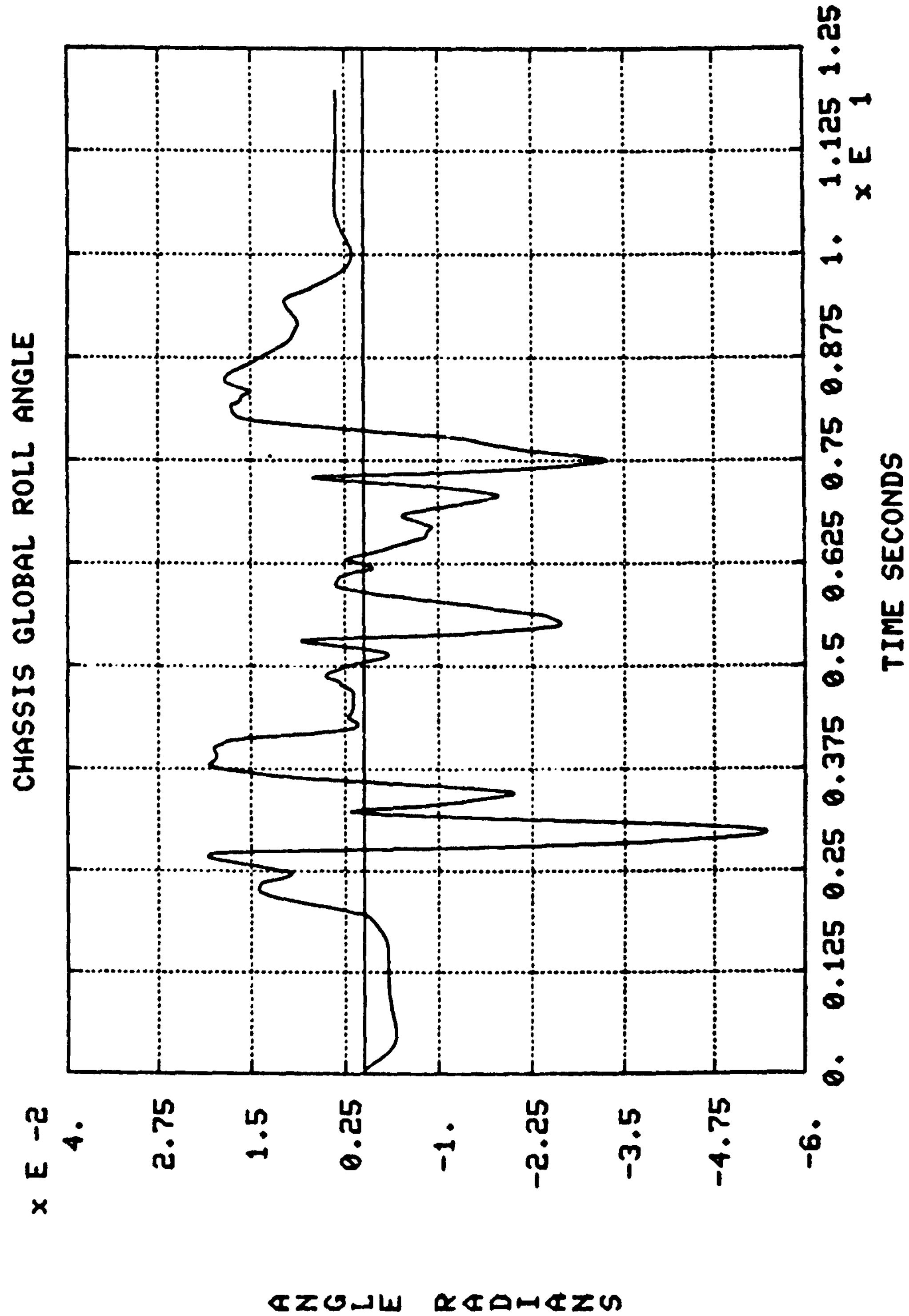


Figure 5-22. Chassis Global Roll Angle

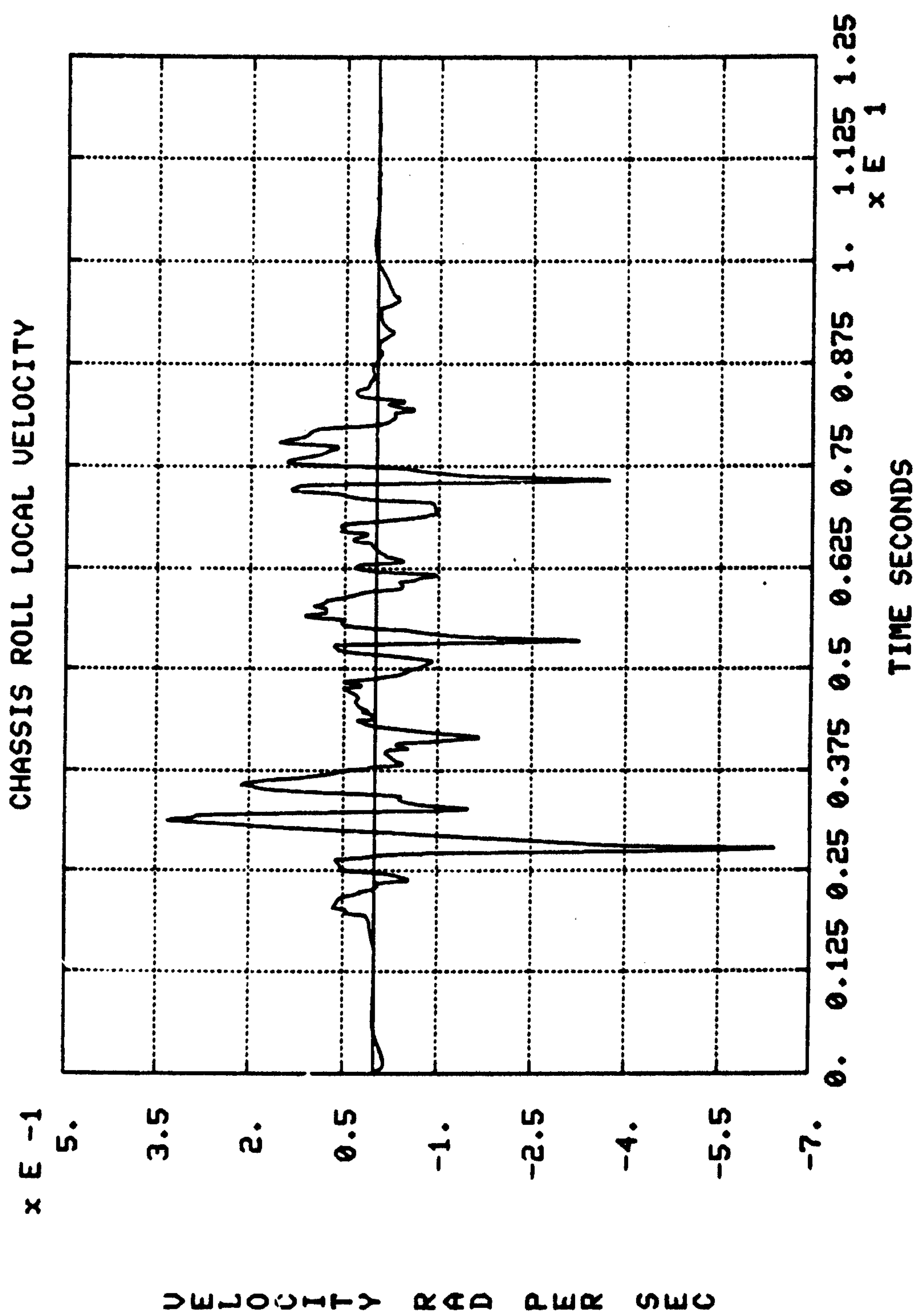


Figure 5-23. Chassis Roll Local Velocity

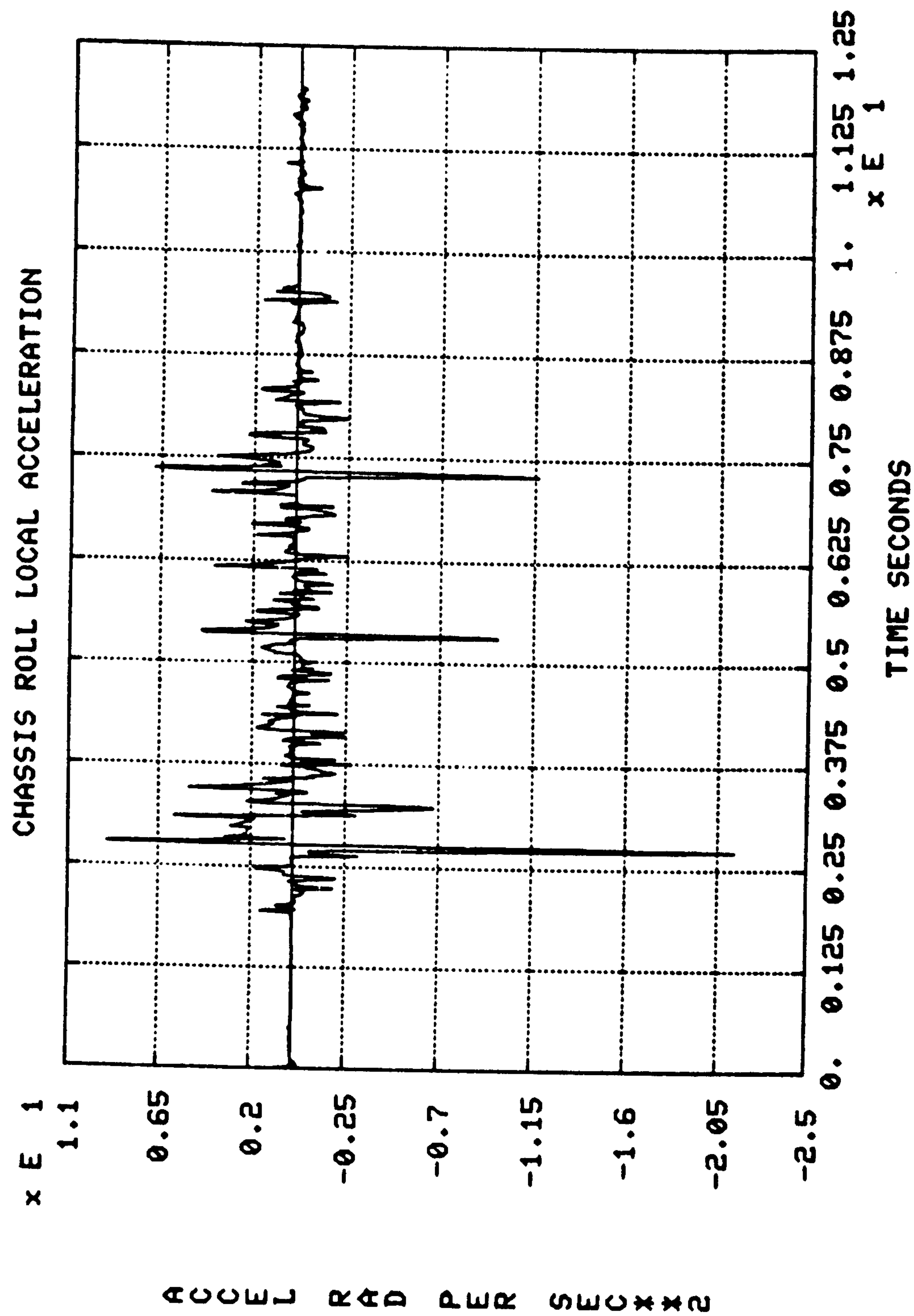


Figure 5-24. Chassis Roll Local Acceleration

Figures 5-25 through 5-27 show the chassis yaw angle, yaw velocity, and yaw acceleration. Positive yaw angle is equivalent to a left turn while a negative yaw angle represents a right turn. After the front wheels clear the first obstacle and are off the ground, and when the front wheels strike the ground upon their return, the forces on the vehicle cause the vehicle to turn towards the left. The maximum yaw angle is less than 3 degrees.

Figures 5-28 through 5-31 show the spring force for the front left, the front right, the rear left, and the rear right springs. Since the spring stiffness is a constant, the spring deflection curves have the same shape. The spring deflections, and likewise the spring forces, are limited by the travel limits of the shock absorbers.

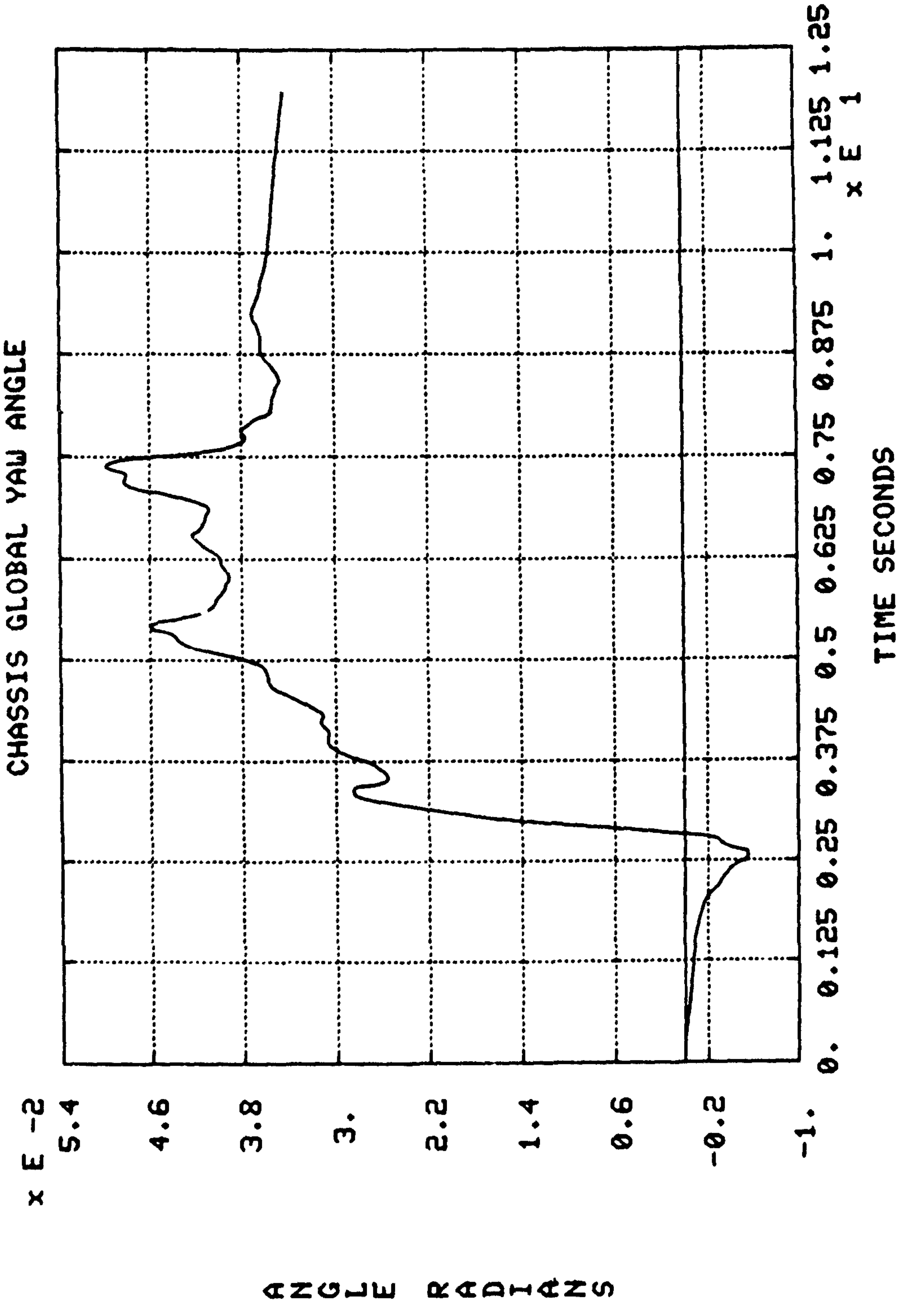
Figures 5-32 through 5-35 show the length of each shock absorber. The shock length is limited by metal stops within the shock as explained in section 5.3.7. titled "Shock Absorbers." Metal-to-metal contact occurs at a compressed length of 12.76 inches and an extended length of 16.48 inches. Shock absorber lengths less than 12.76 inches are shown. This is a result of modeling the metal stops as a linear stiff spring element. Penetration into the metal stops represents the deflection and buckling of the internal shock absorber components.

Figures 5-36 through 5-39 show the impact forces generated when the shock makes metal-to-metal contact. The front left shock and the front right shock reach the metal-to-metal condition in compression only after clearing the first obstacle. The front shock reaches the metal-to-metal condition in extension seven times, once after clearing each of the seven obstacles. These events occur as the front wheels leave the ground. Compression of the spring causes the suspension unit to "open up." Metal stops within the shock limit the amount of travel. The rear left and rear right shocks reach the metal-to-metal condition in compression several times. The rear right shock experiences this condition more frequently and to a greater degree. Having the chassis CG located rearward and to the right of the vehicle is one of the factors causing these events to occur more frequently at the right rear suspension.

Figures 5-40 through 5-43 show the relative velocity of each shock absorber. Negative velocity represents compression and positive velocity represents extension.

Figures 5-44 through 5-47 give the total force generated by the shock absorber. The total force is the sum of the damping force, metal-to-metal contact impact force, and friction. Spikes within the curves are generally a result of the impact forces caused by the shock reaching the metal-to-metal condition.

Figures 5-48 through 5-51 show the tire deflection for the front left, the front right, the rear left, and the rear right tires. At zero tire



igure 5-25. Chassis Global Yaw Angle

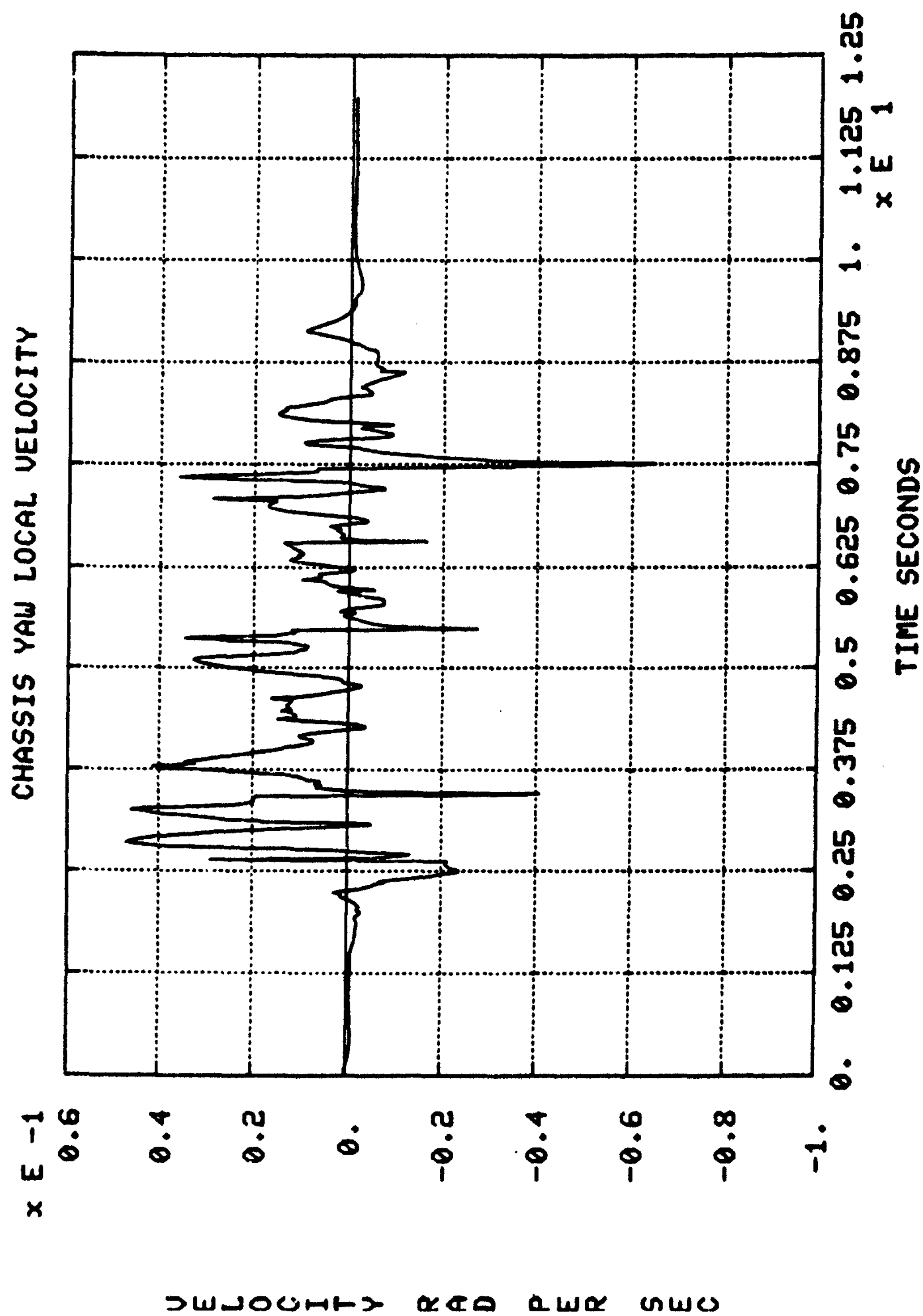


Figure 5-26. Chassis Yaw Local Velocity

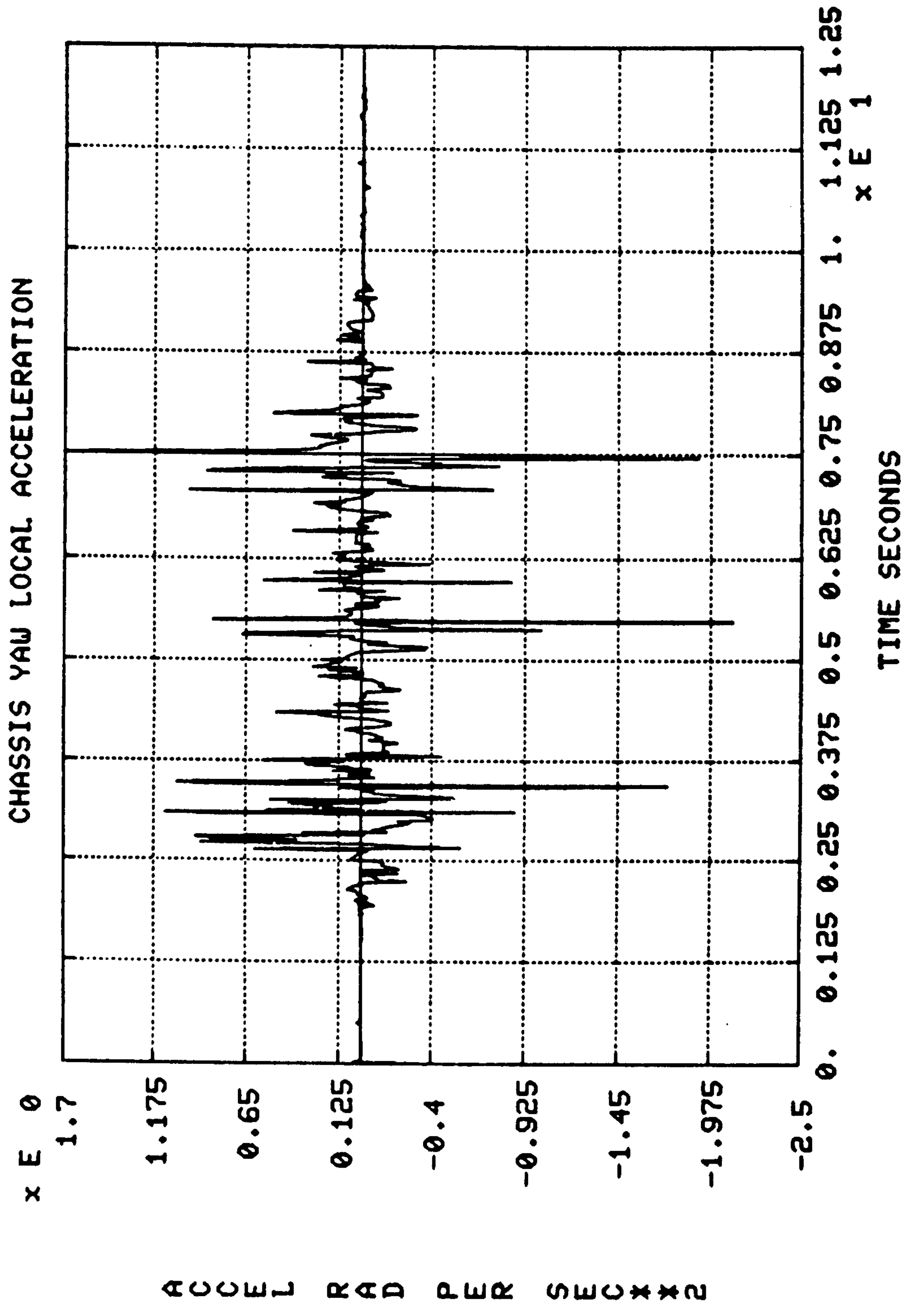


Figure 5-27. Chassis Yaw Local Acceleratio.

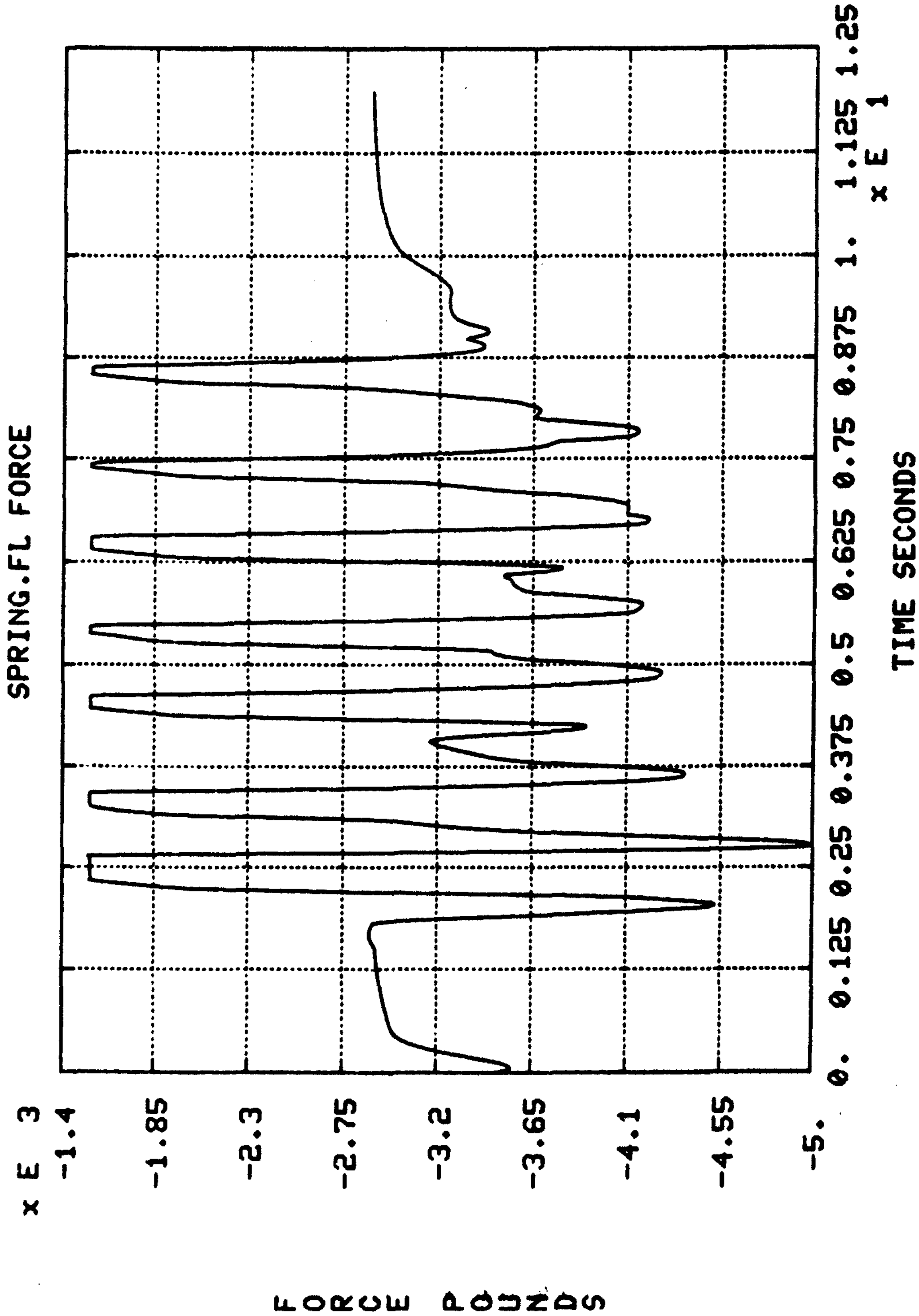


Figure 5-28. Front Left Spring Force

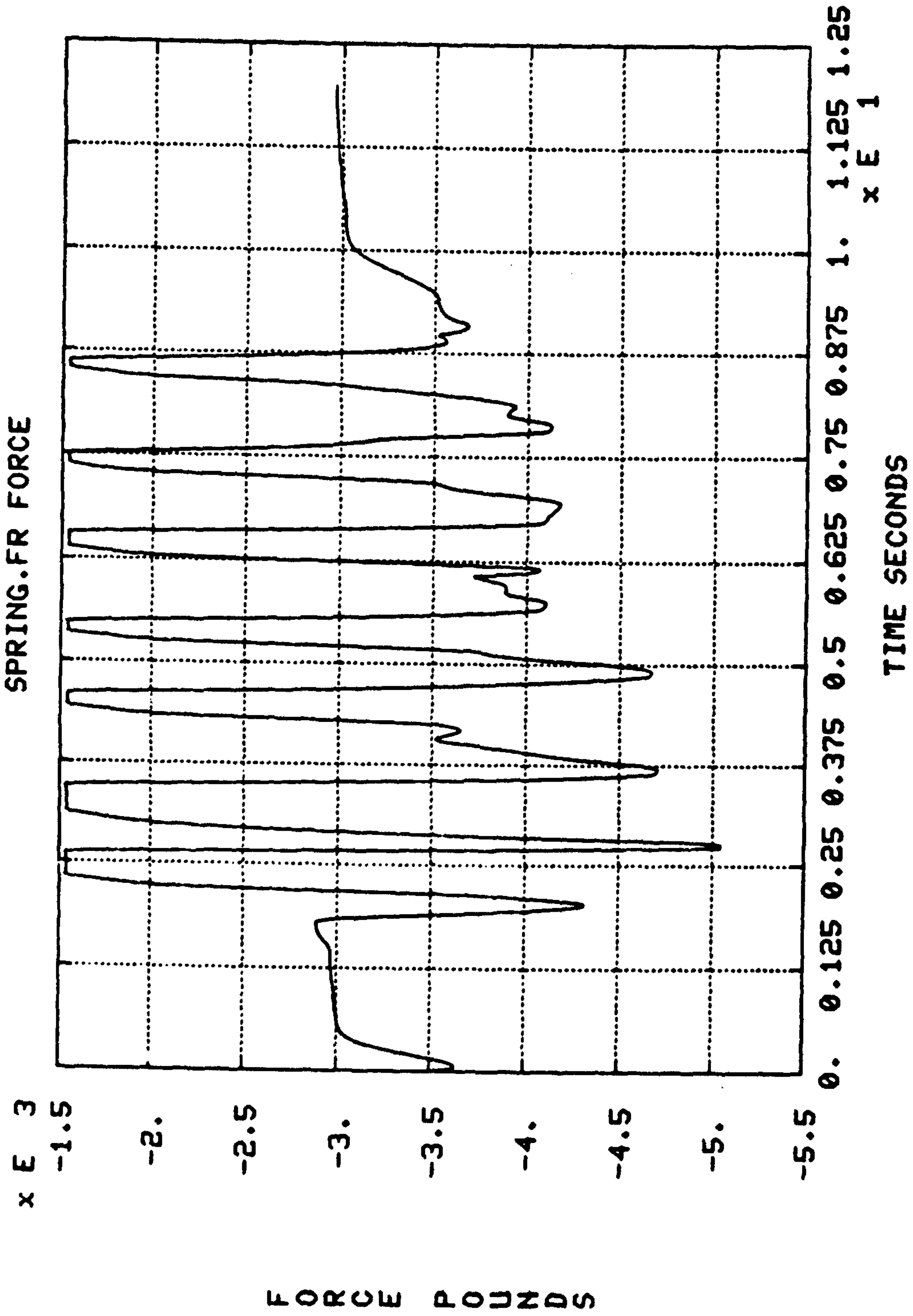


Figure 5-29. Front Right Spring Force

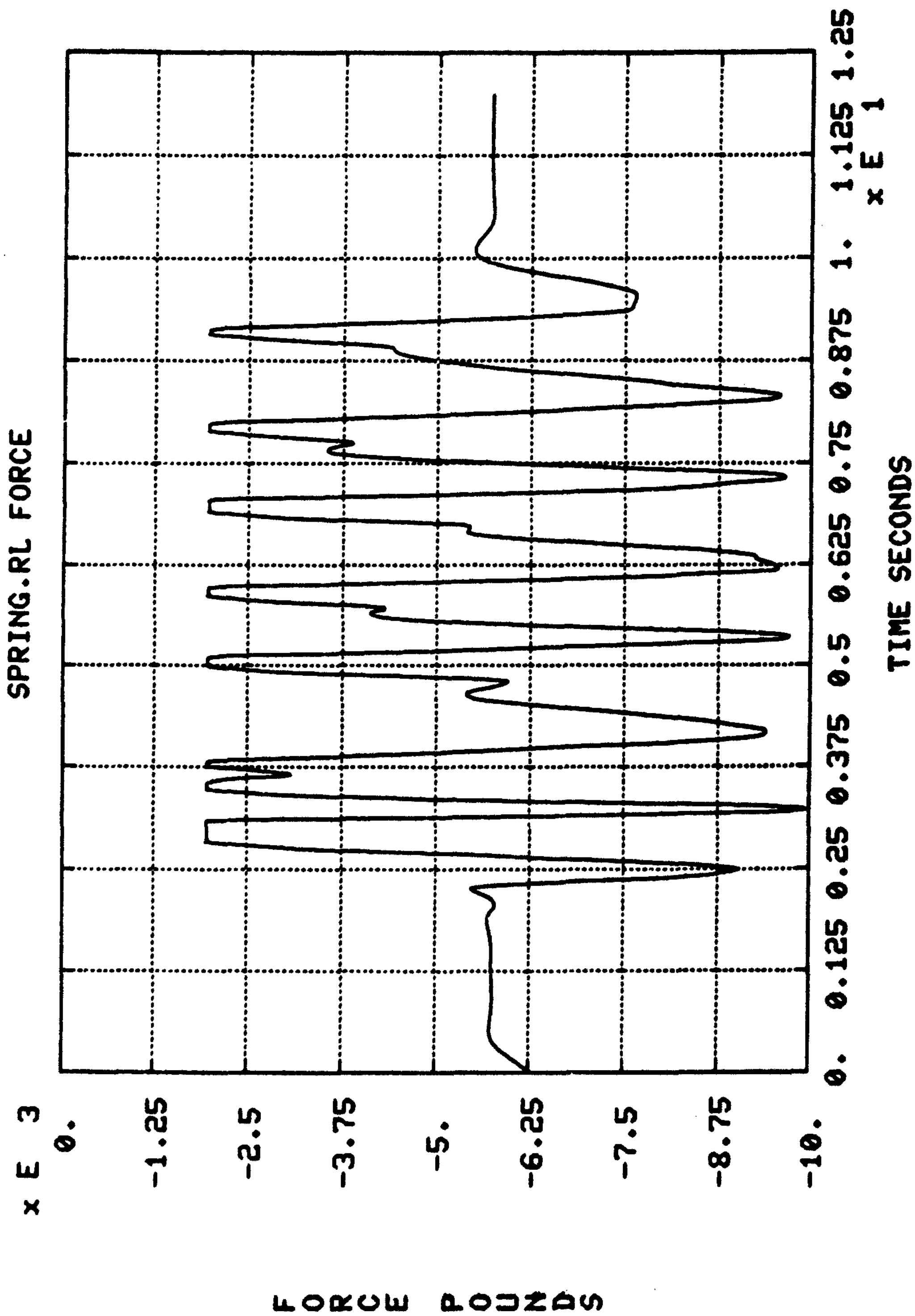


Figure 5-30. Rear Left Spring Force

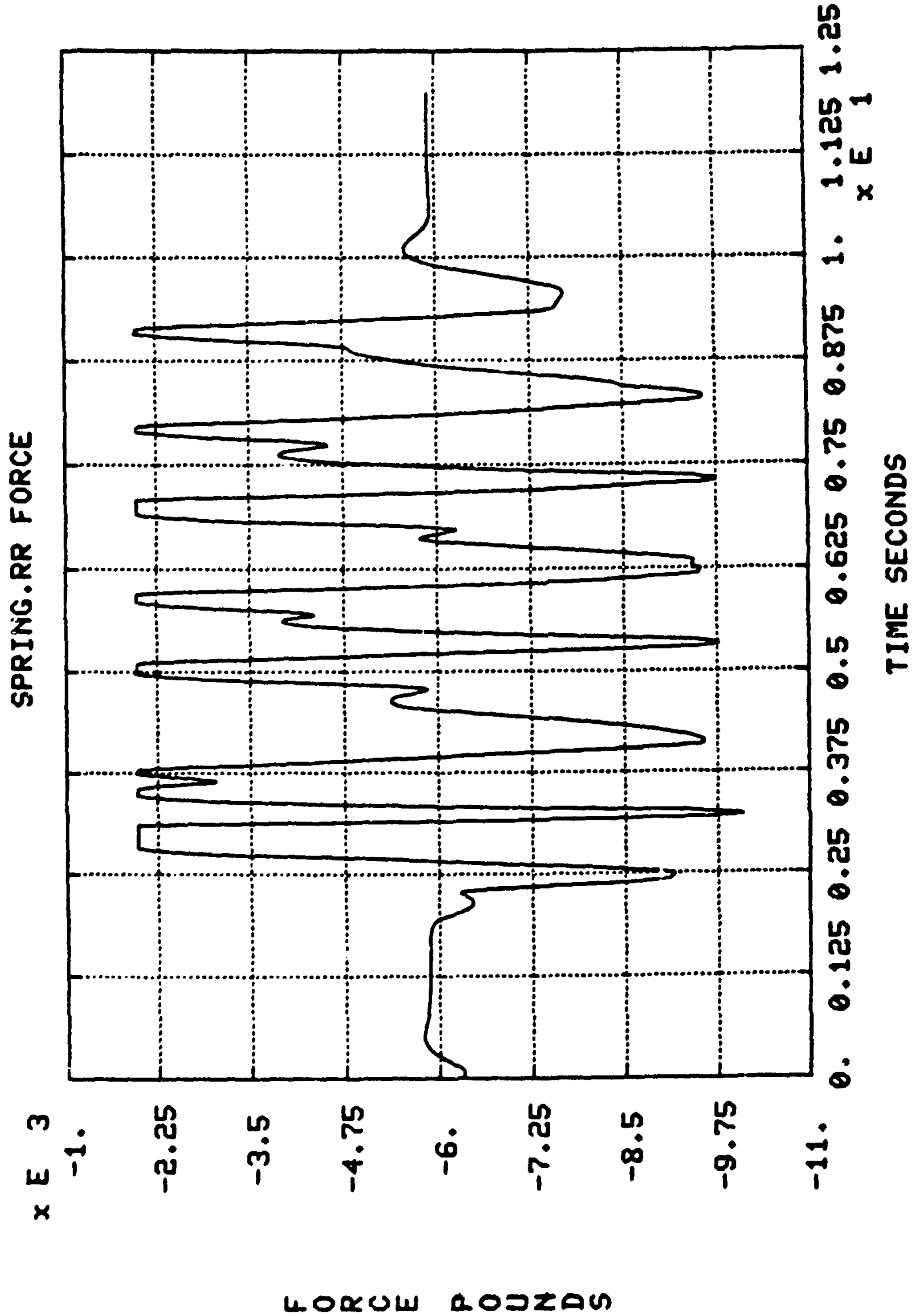


Figure 5-31. Rear Right Spring Force

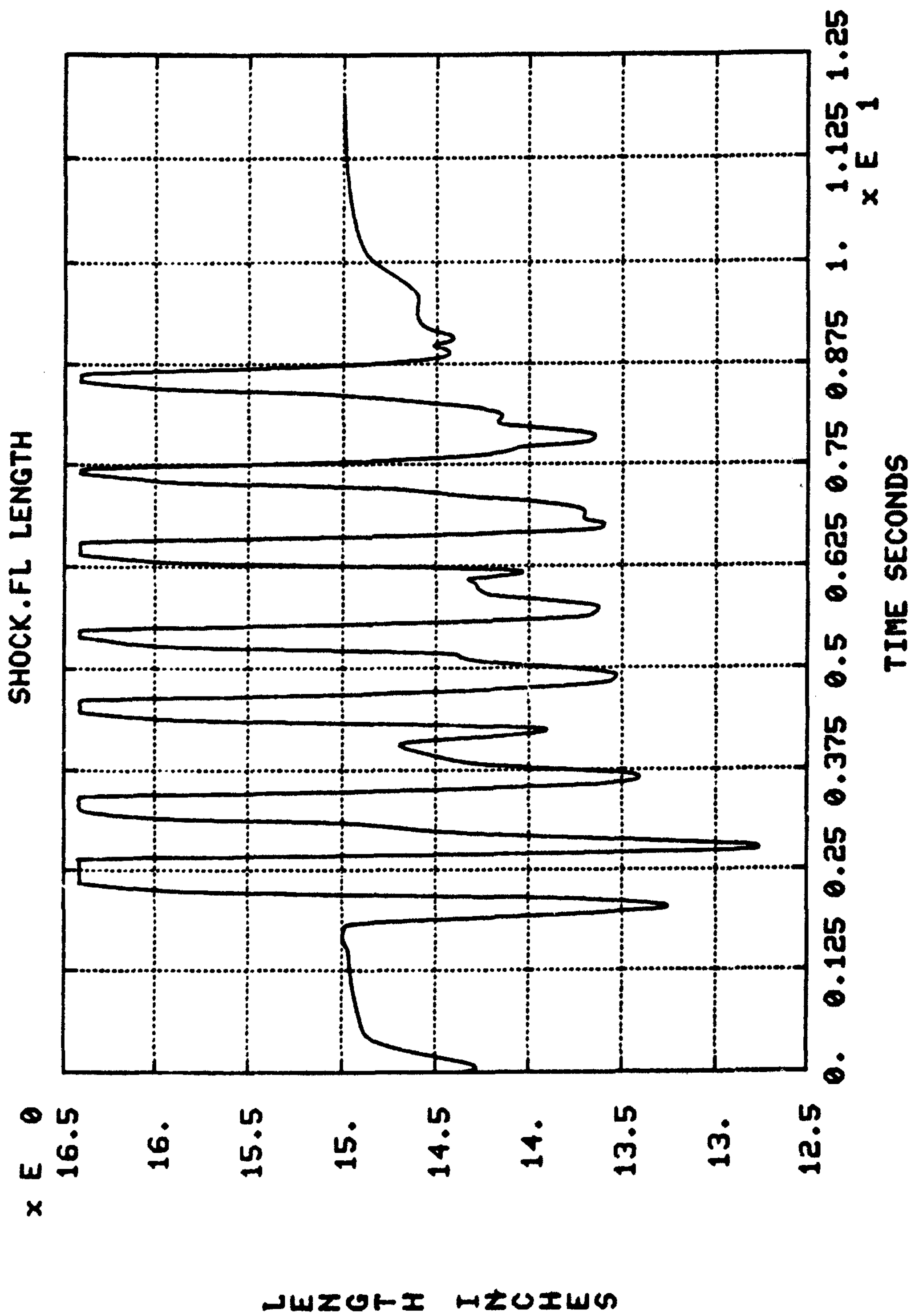


Figure 5-32. Front Left Shock Length

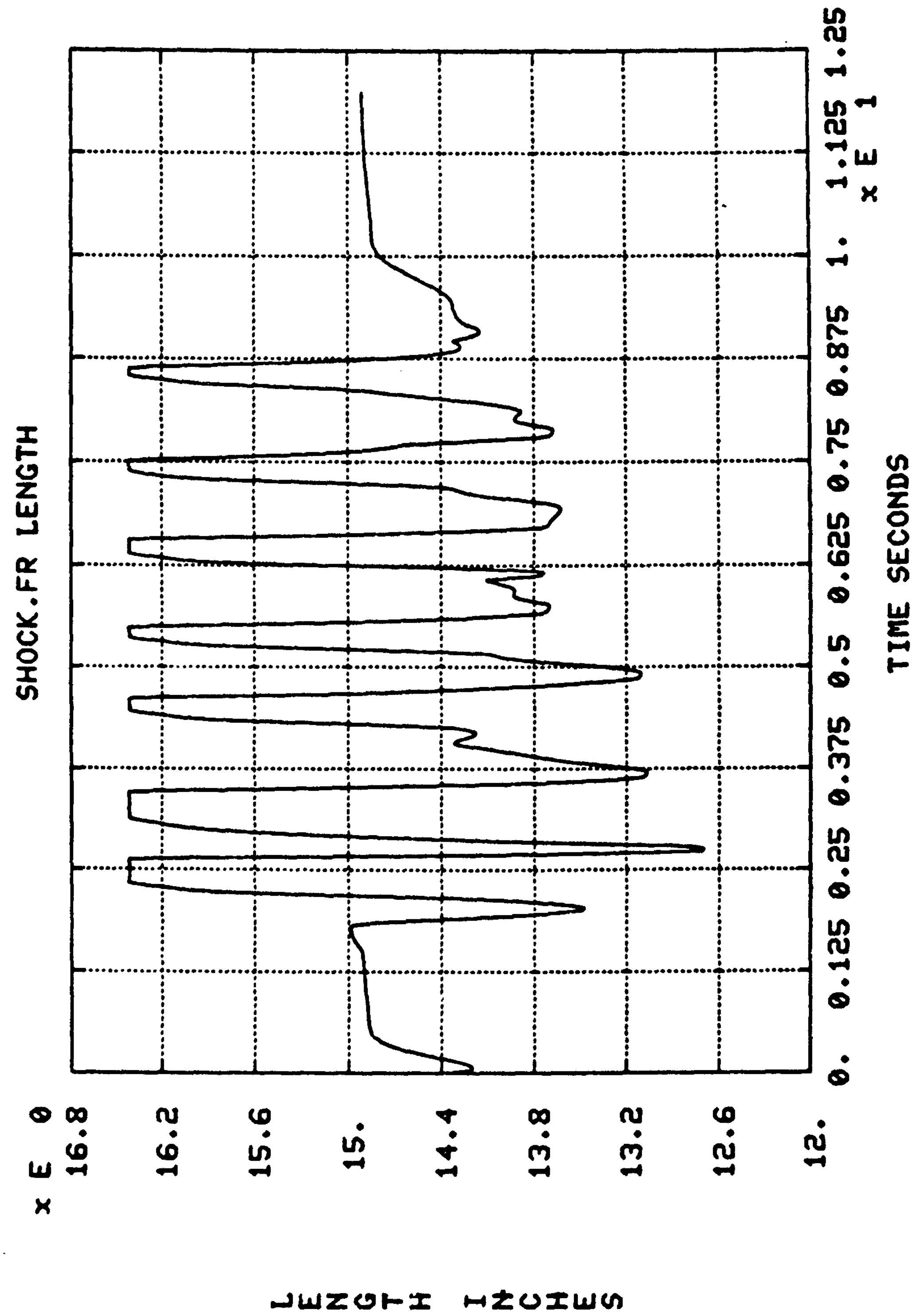


Figure 5-33. Front Right Shock Length

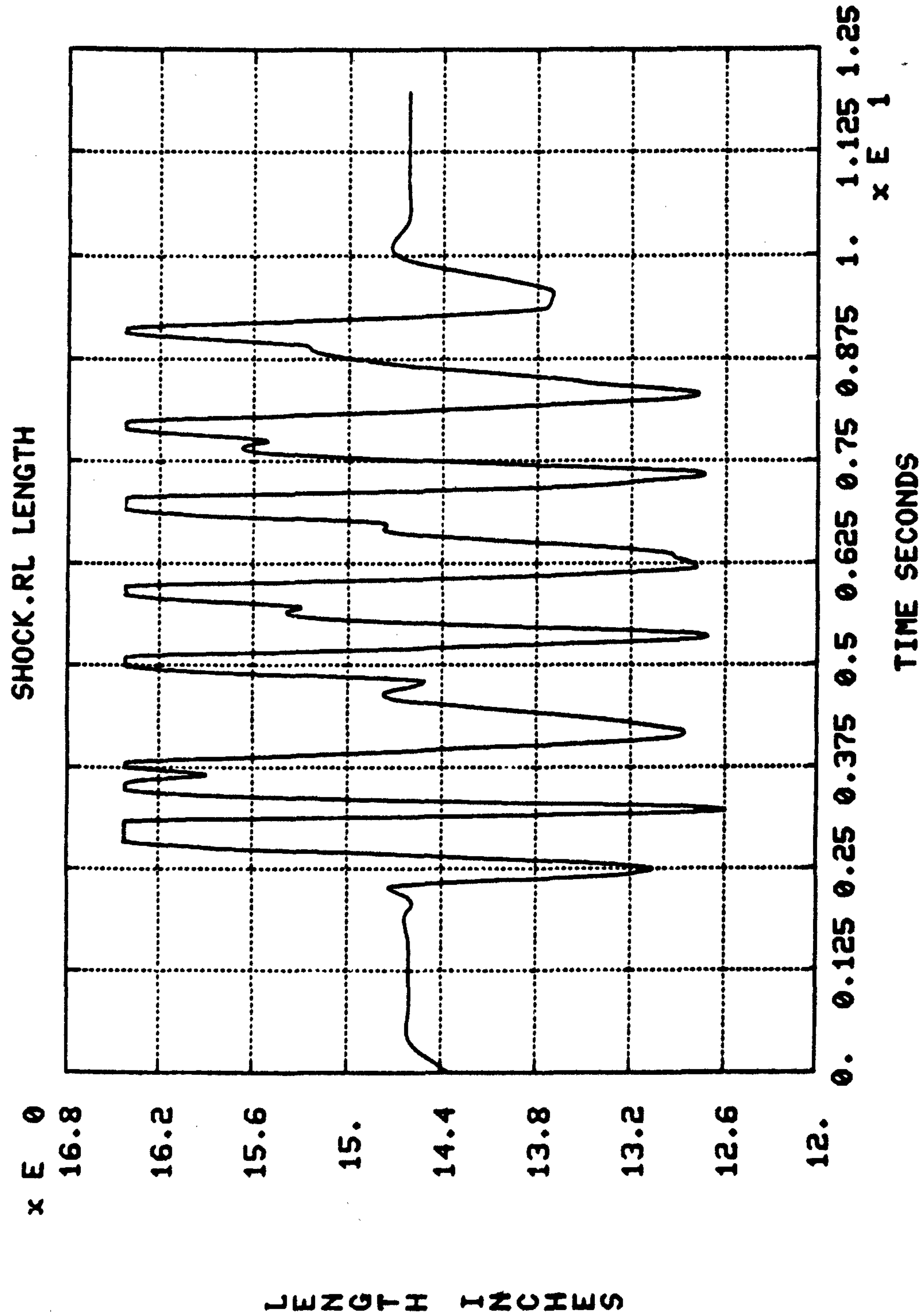


Figure 5-34. Rear Left Shock Length

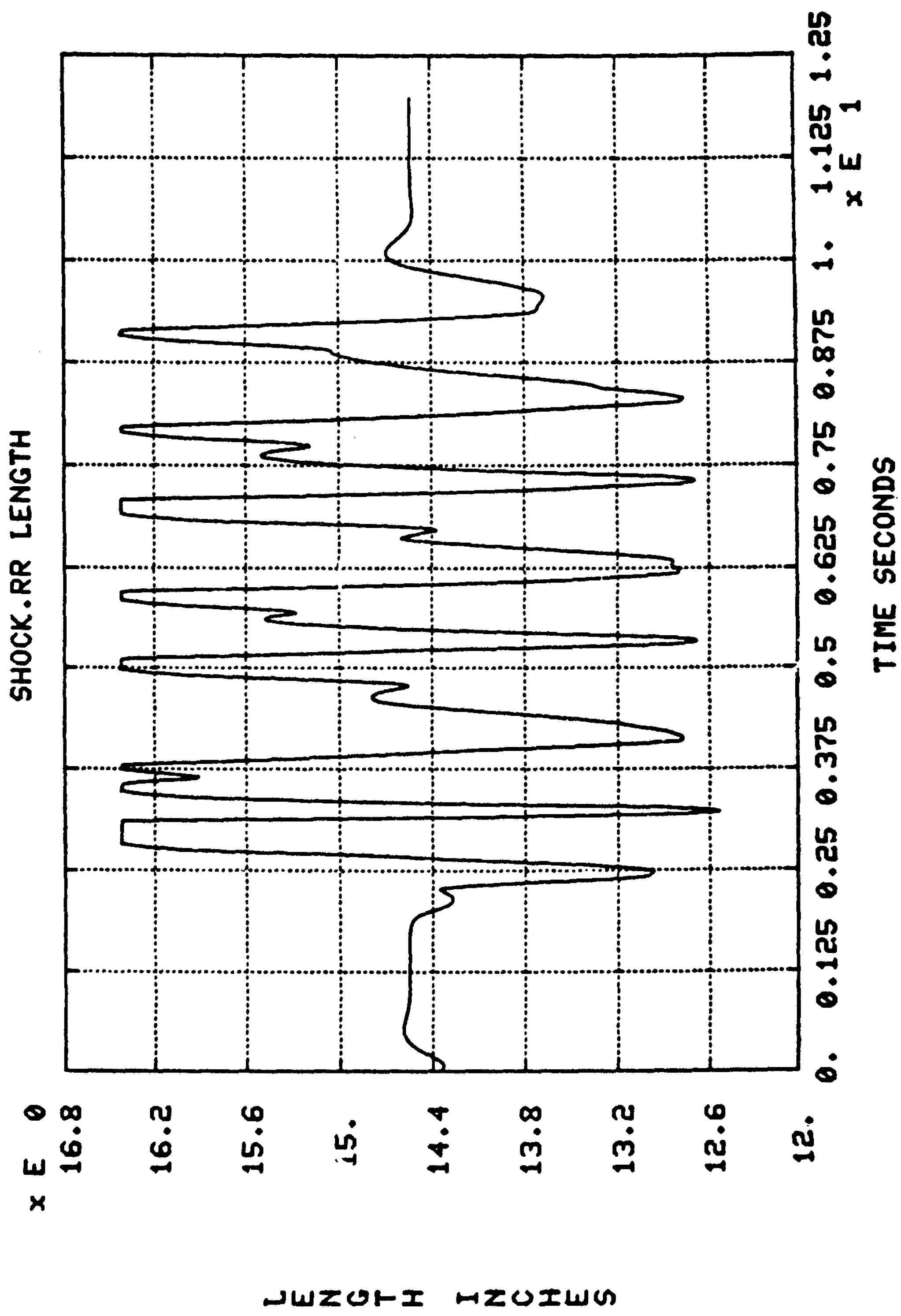


Figure 5-35. Rear Right Shock Length

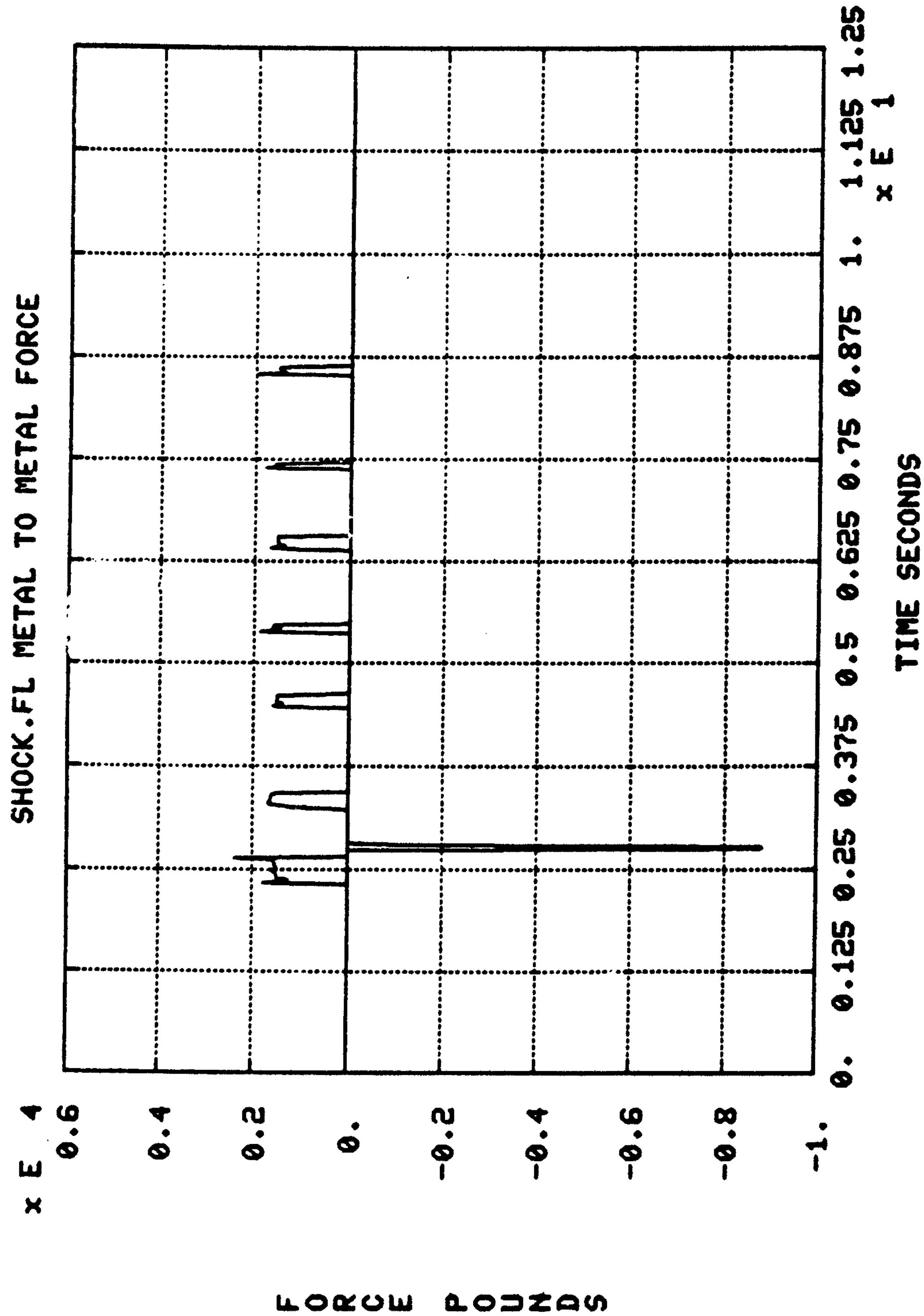


Figure 5-36. Front Left Shock Metal to Metal Force

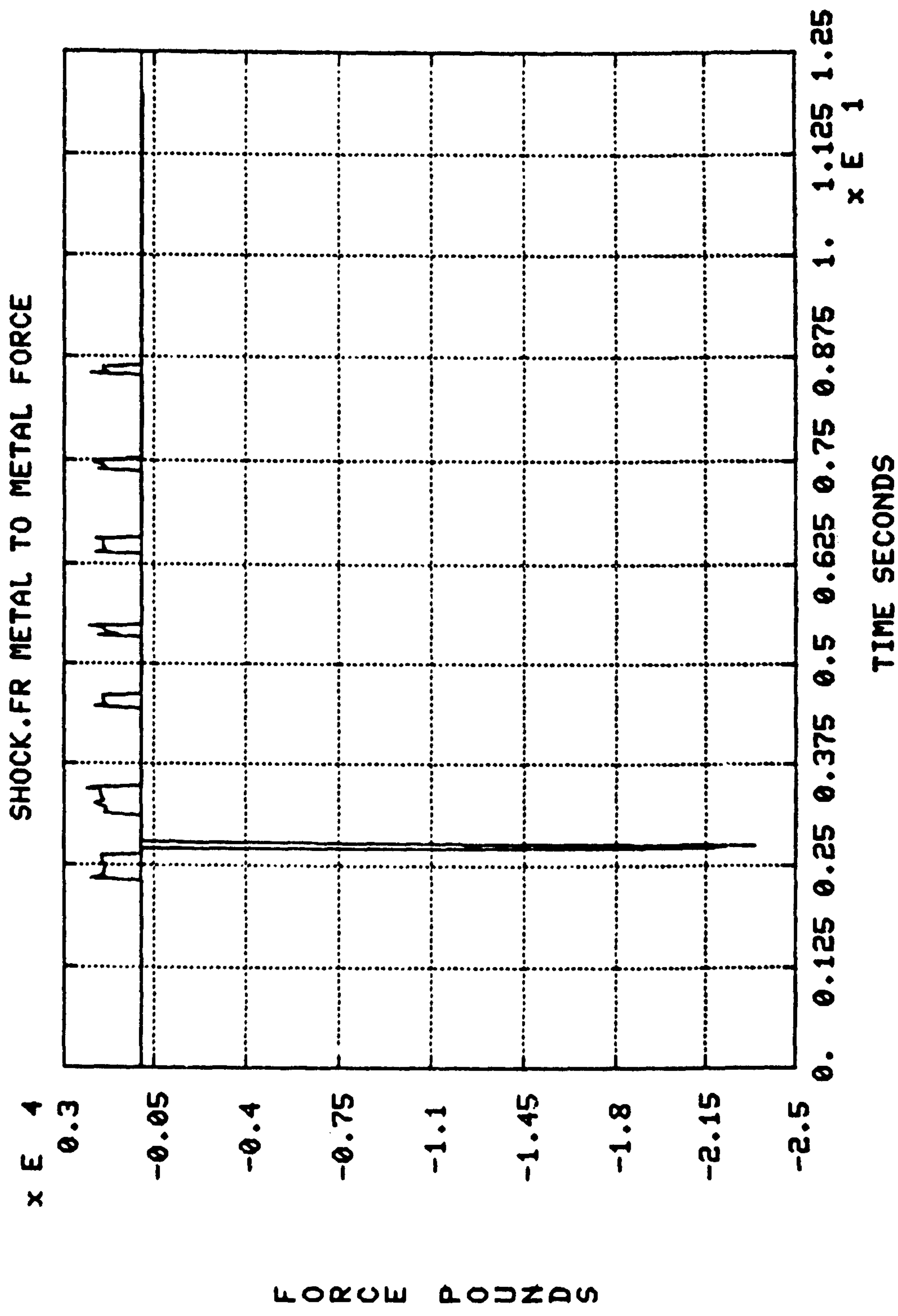


Figure 5-37. Front Right Shock Metal to Metal Force

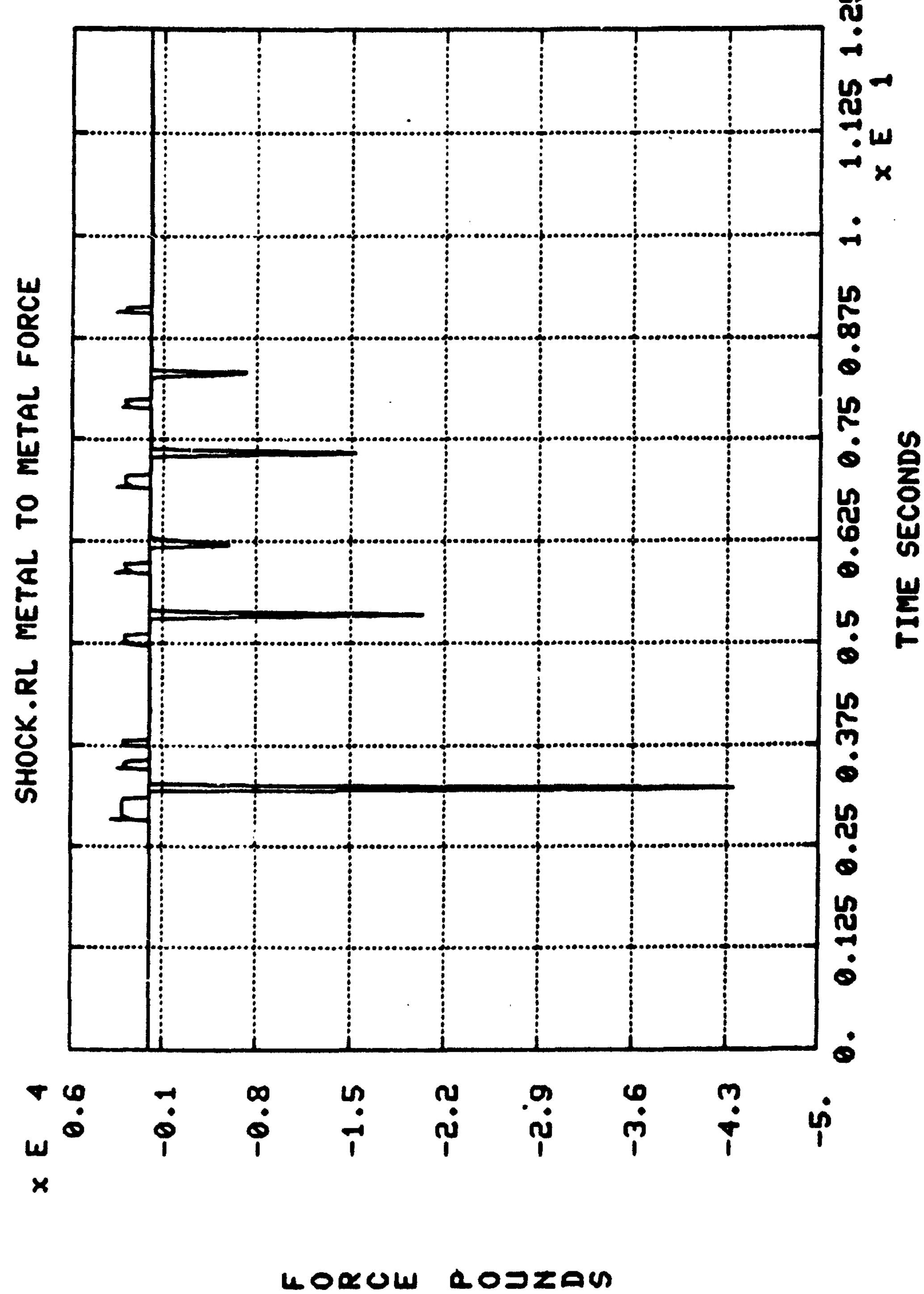


Figure 5-38. Rear Left Shock Metal to Metal Force

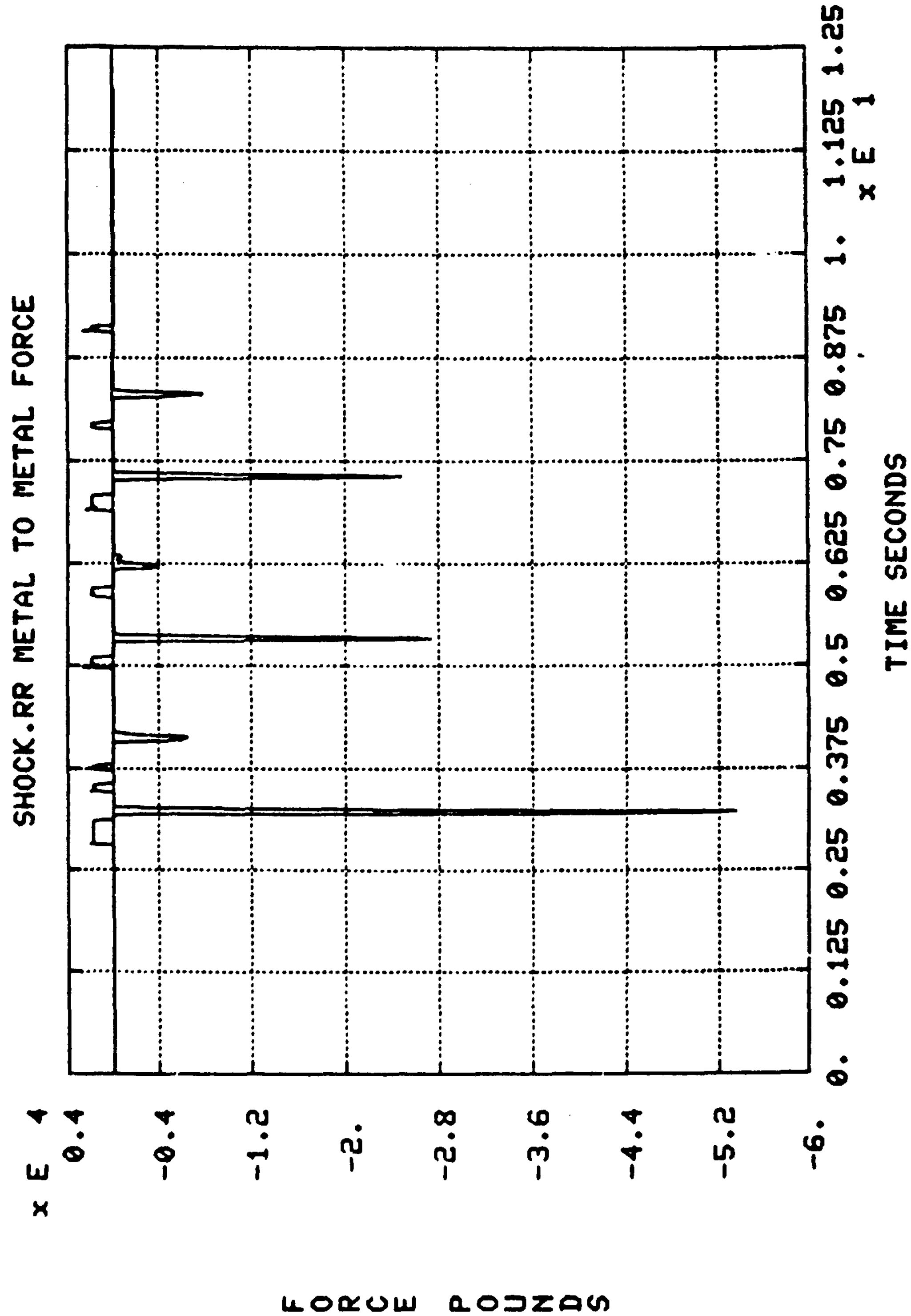


Figure 5-39. Rear Right Shock Metal to Metal Force

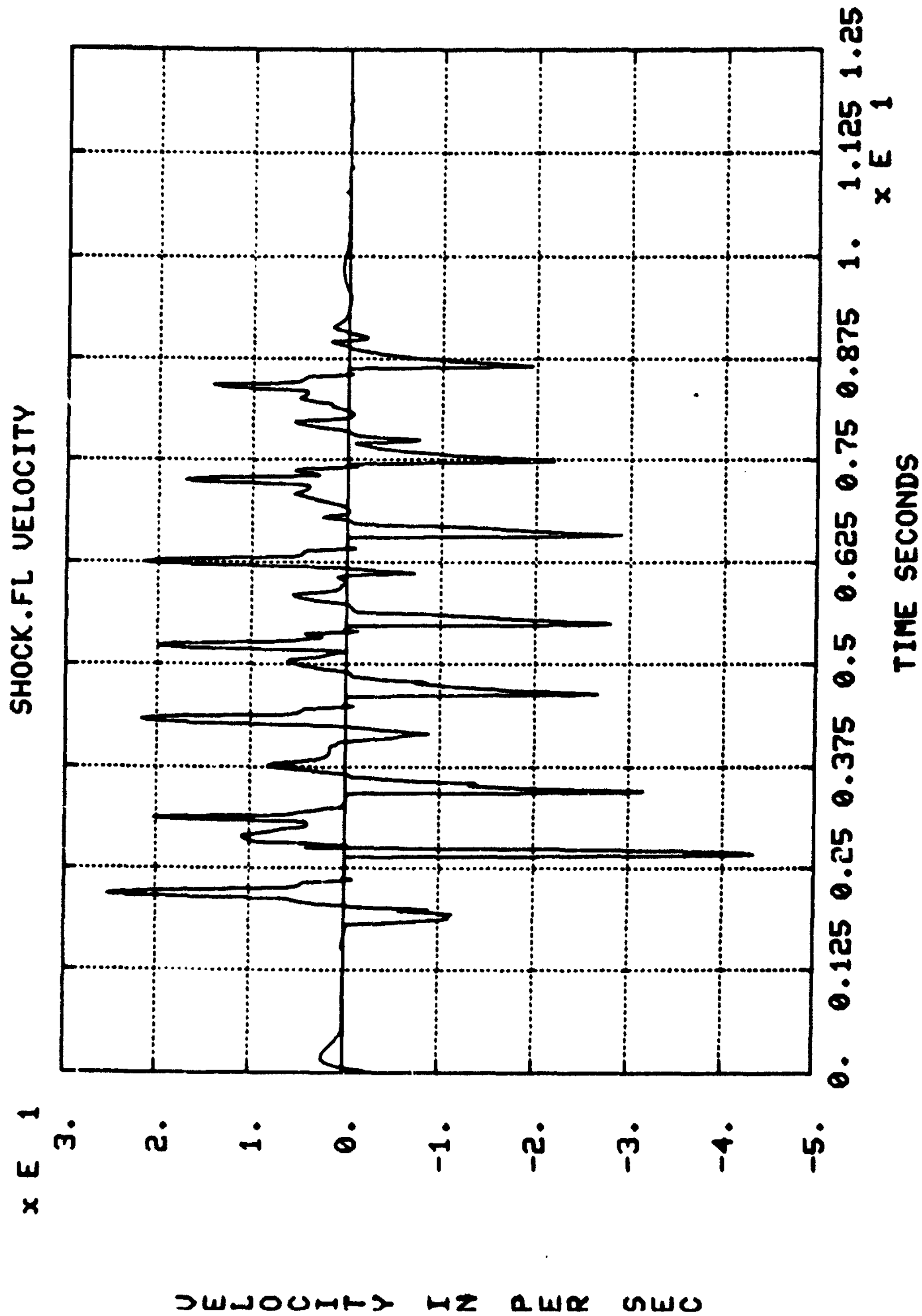
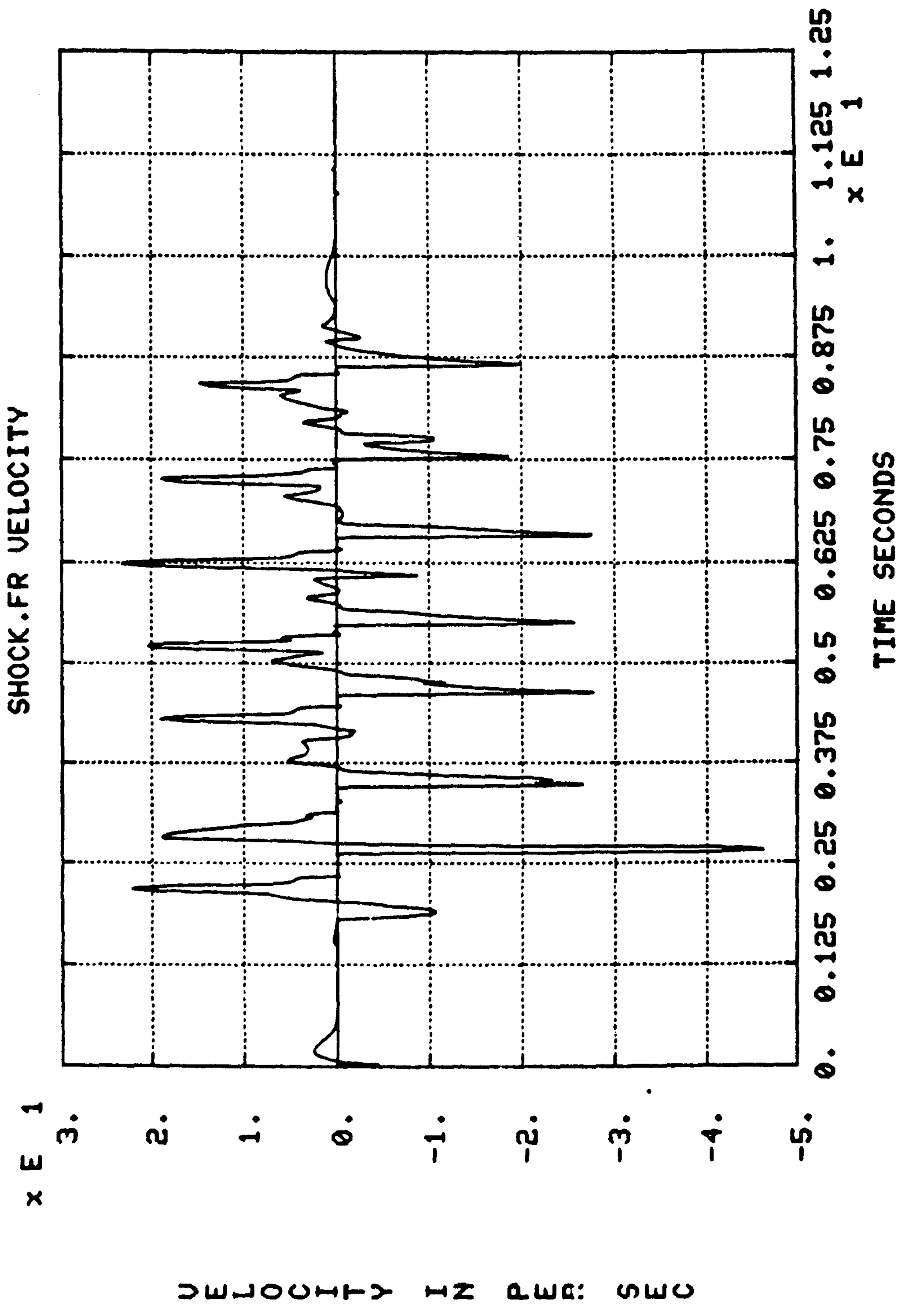


Figure 5-46. Front Left Shock Velocity



ure 5-41. Front Right Shock Velocity

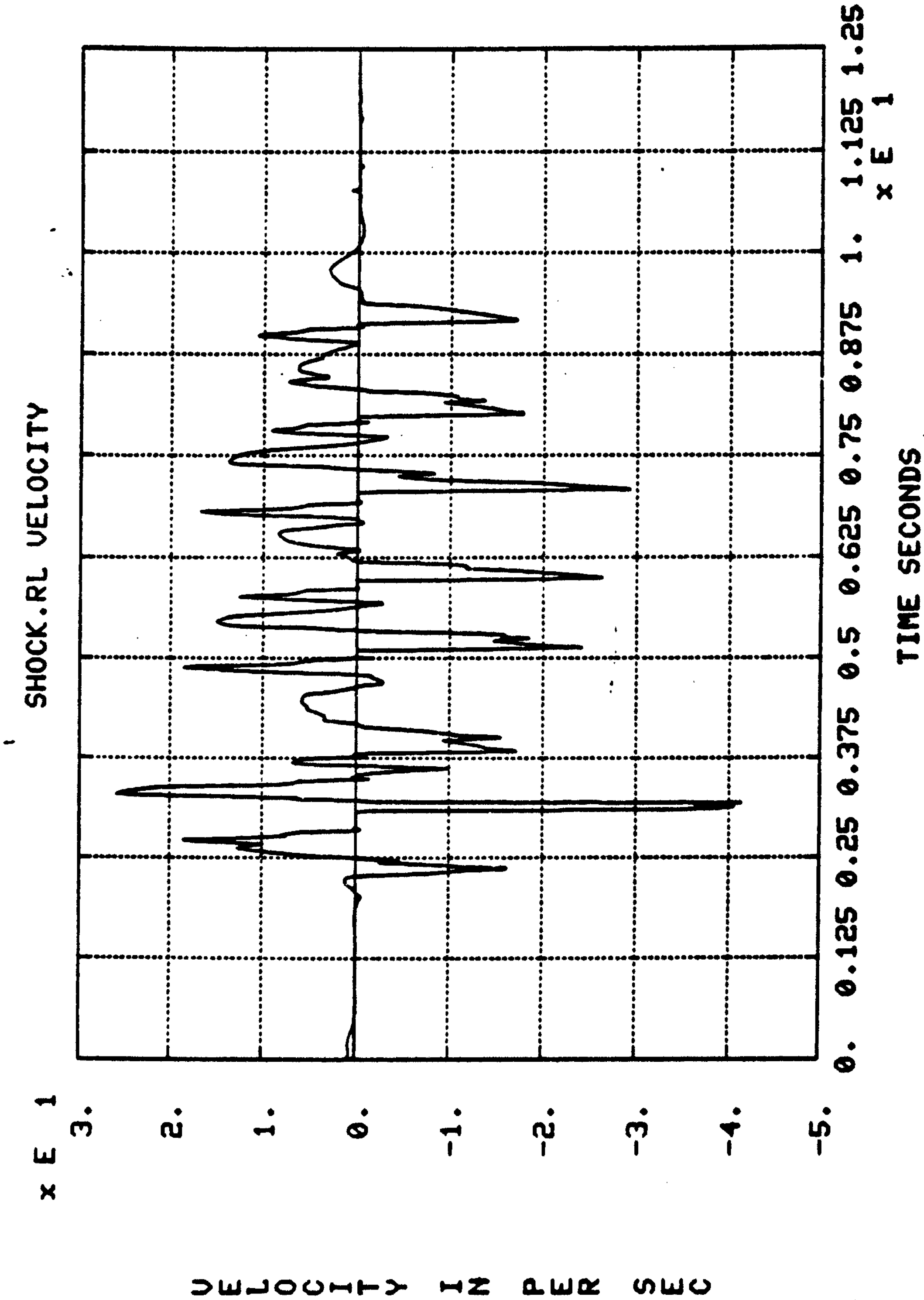


Figure 5-42. Rear Left Shock Velocity

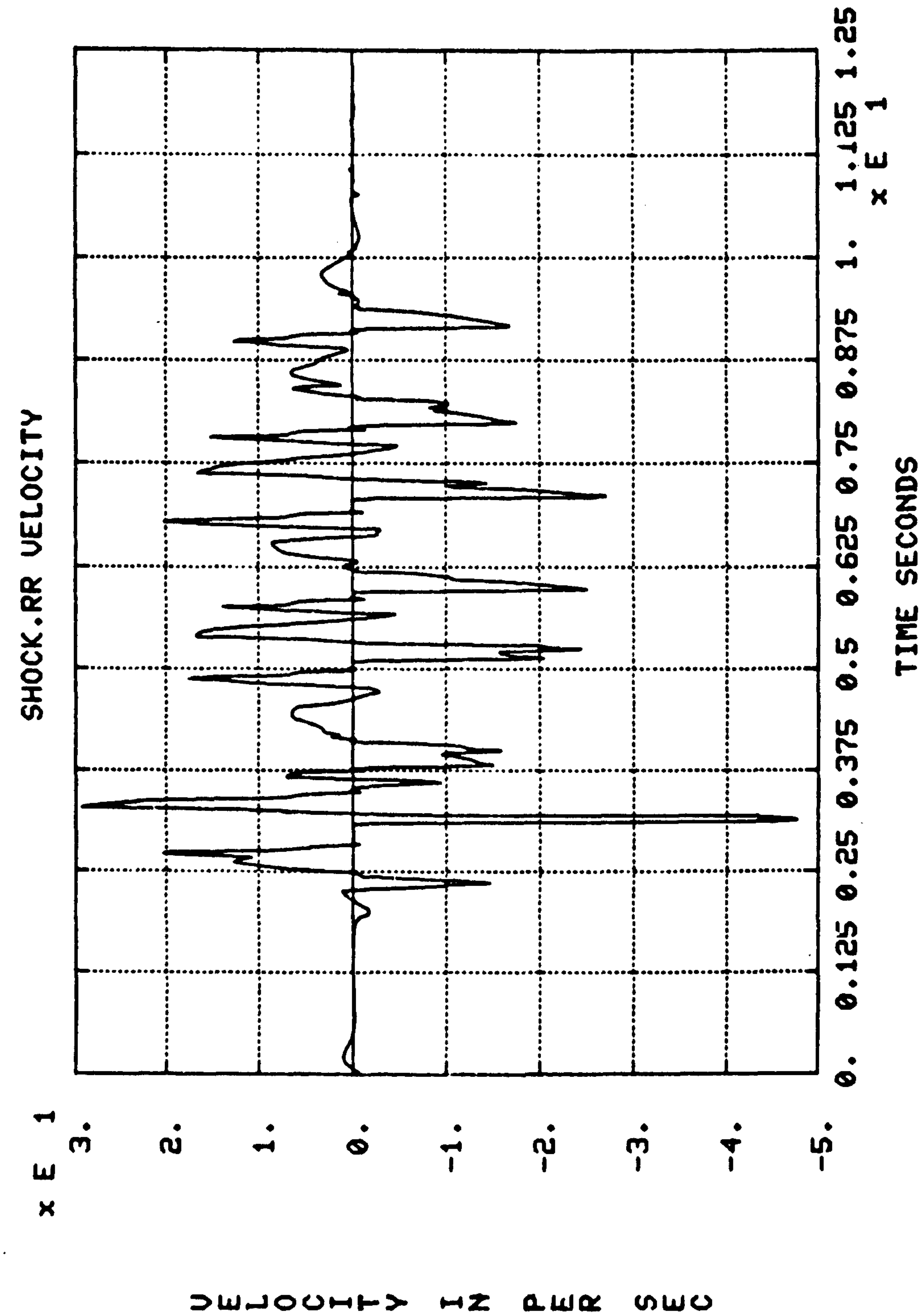


Figure 5-43. Rear Right Shock Velocity

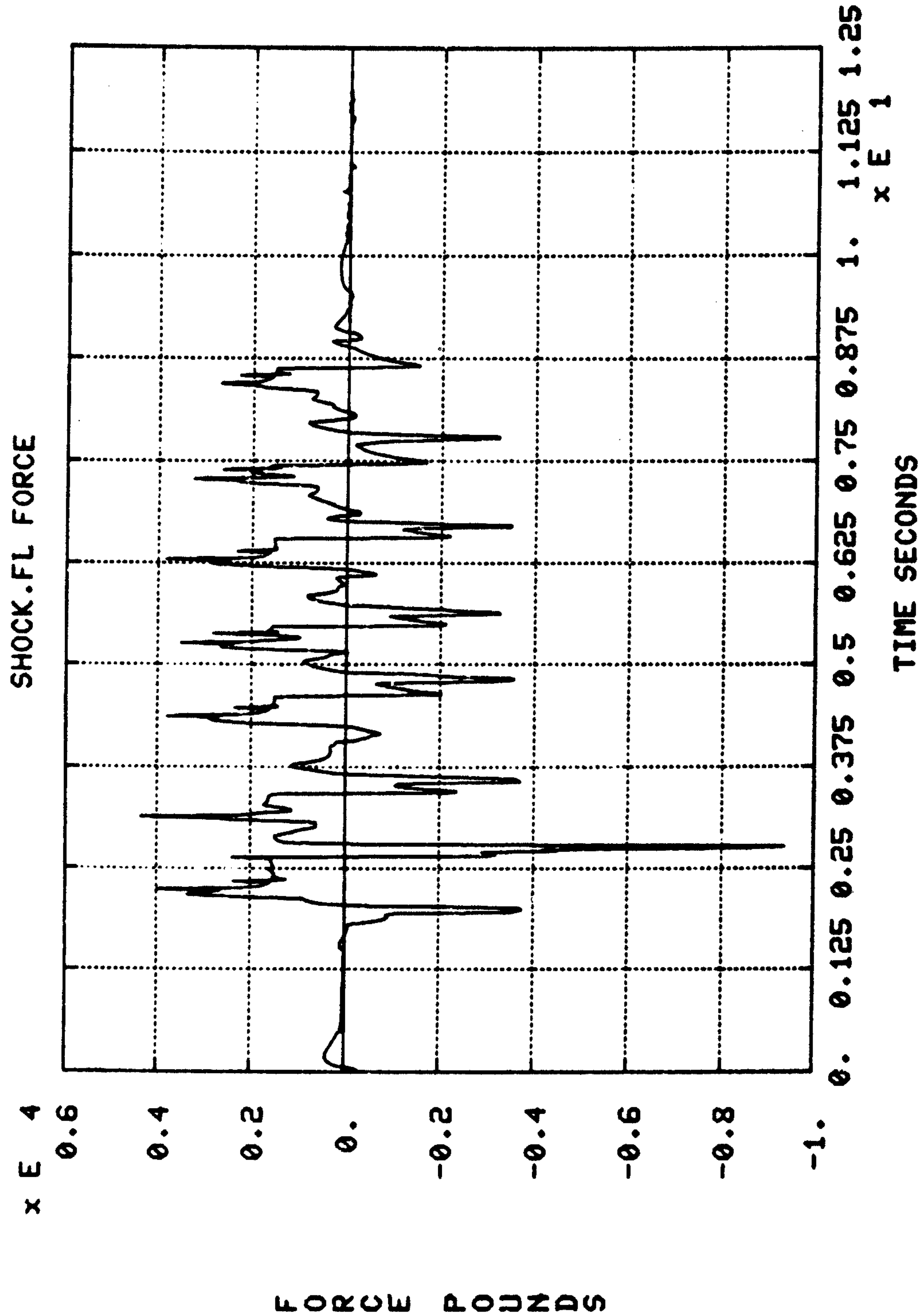


Figure 5-44. Front Left Shock Force

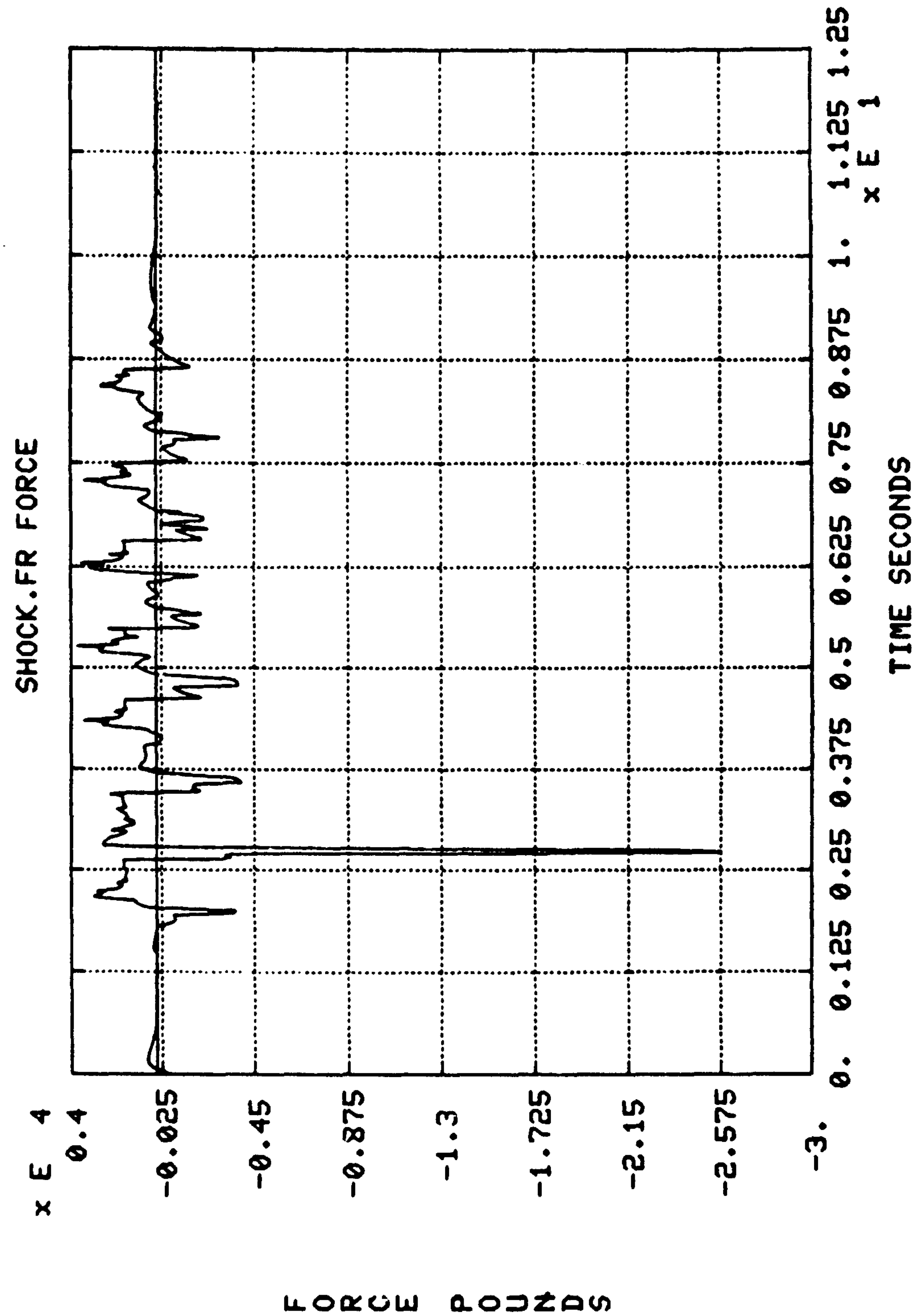


Figure 5-45. Front Right Shock Force

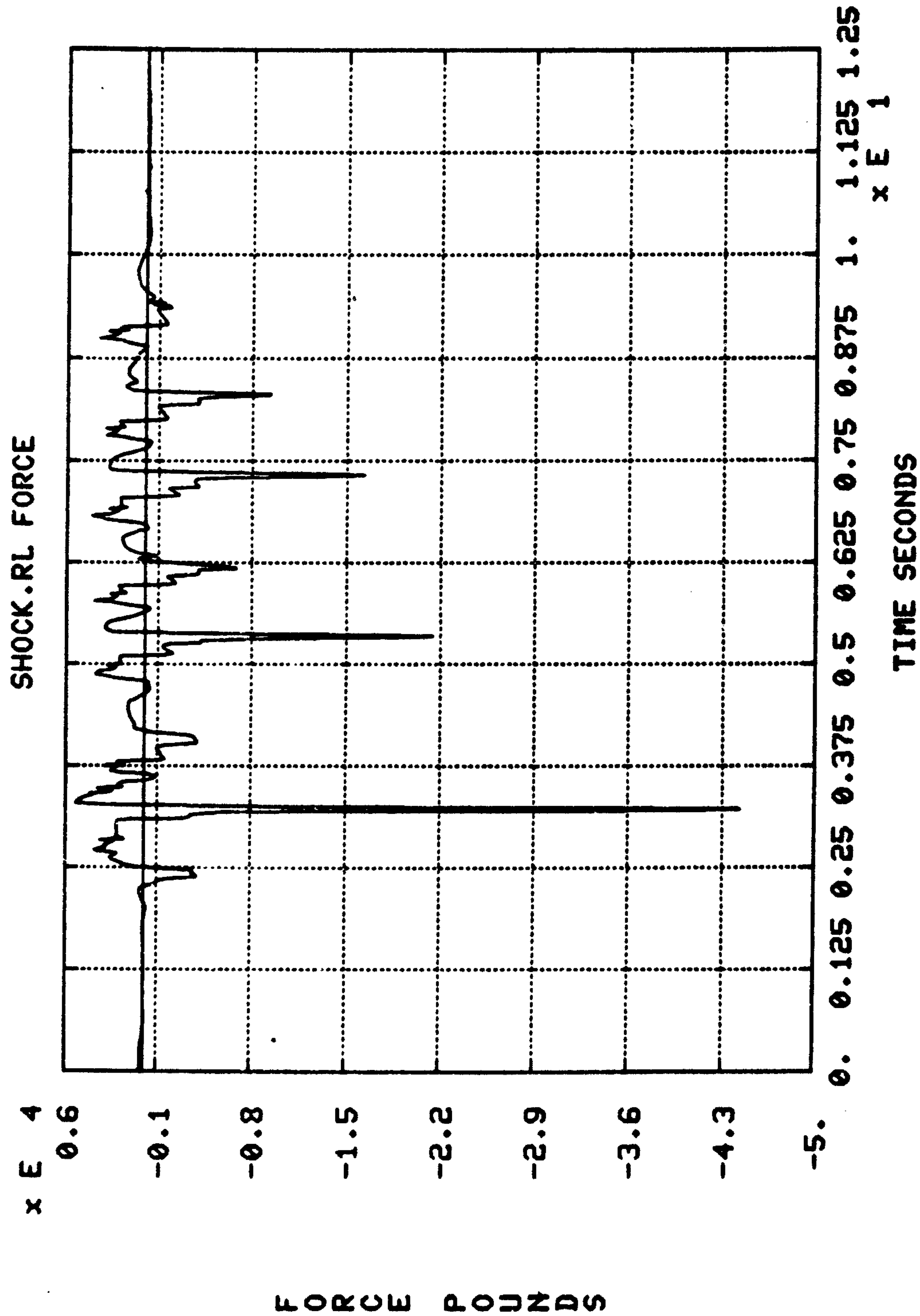


Figure 5-46. Rear Left Shock Force

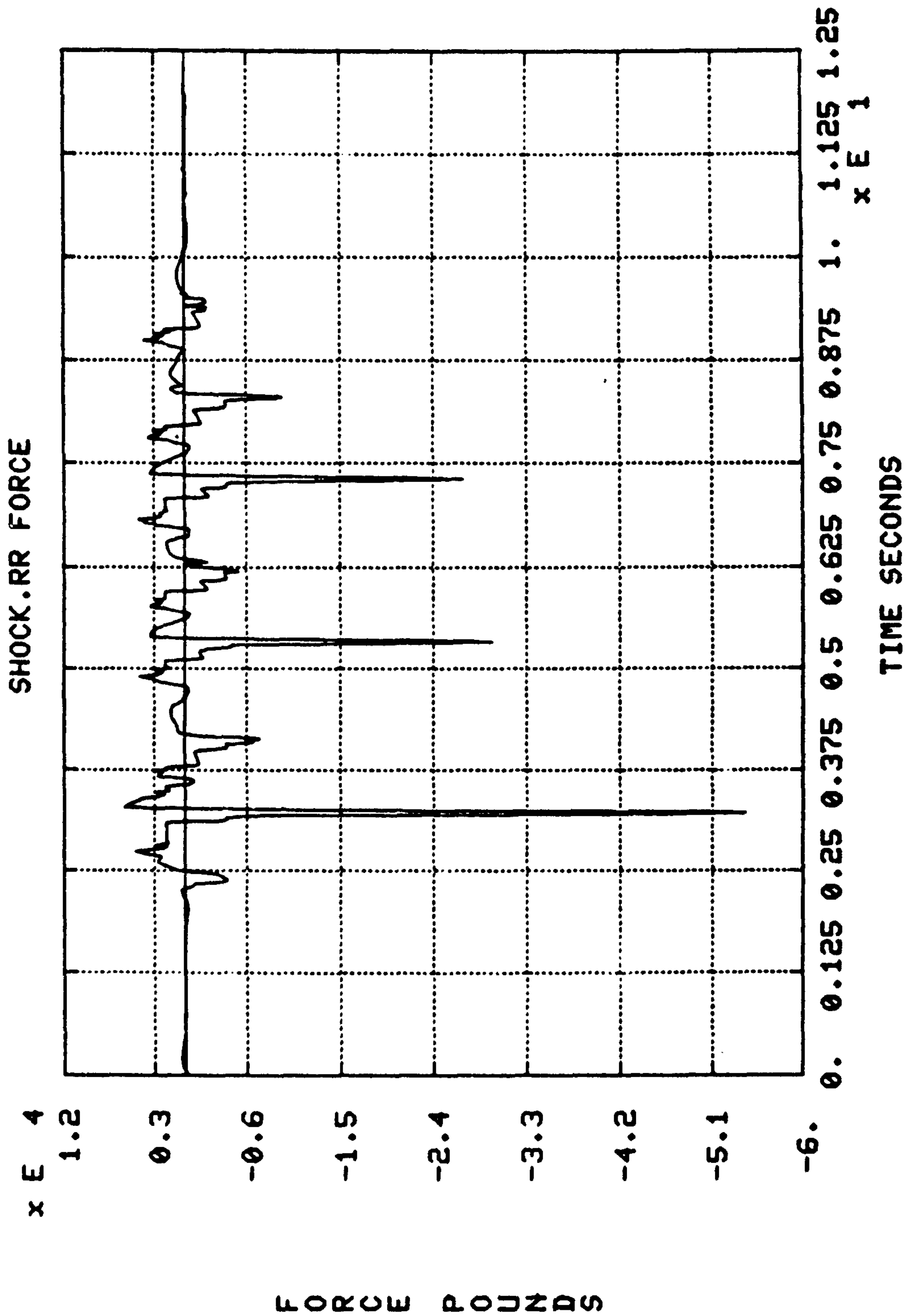


Figure 5-47. Rear Right Shock Force

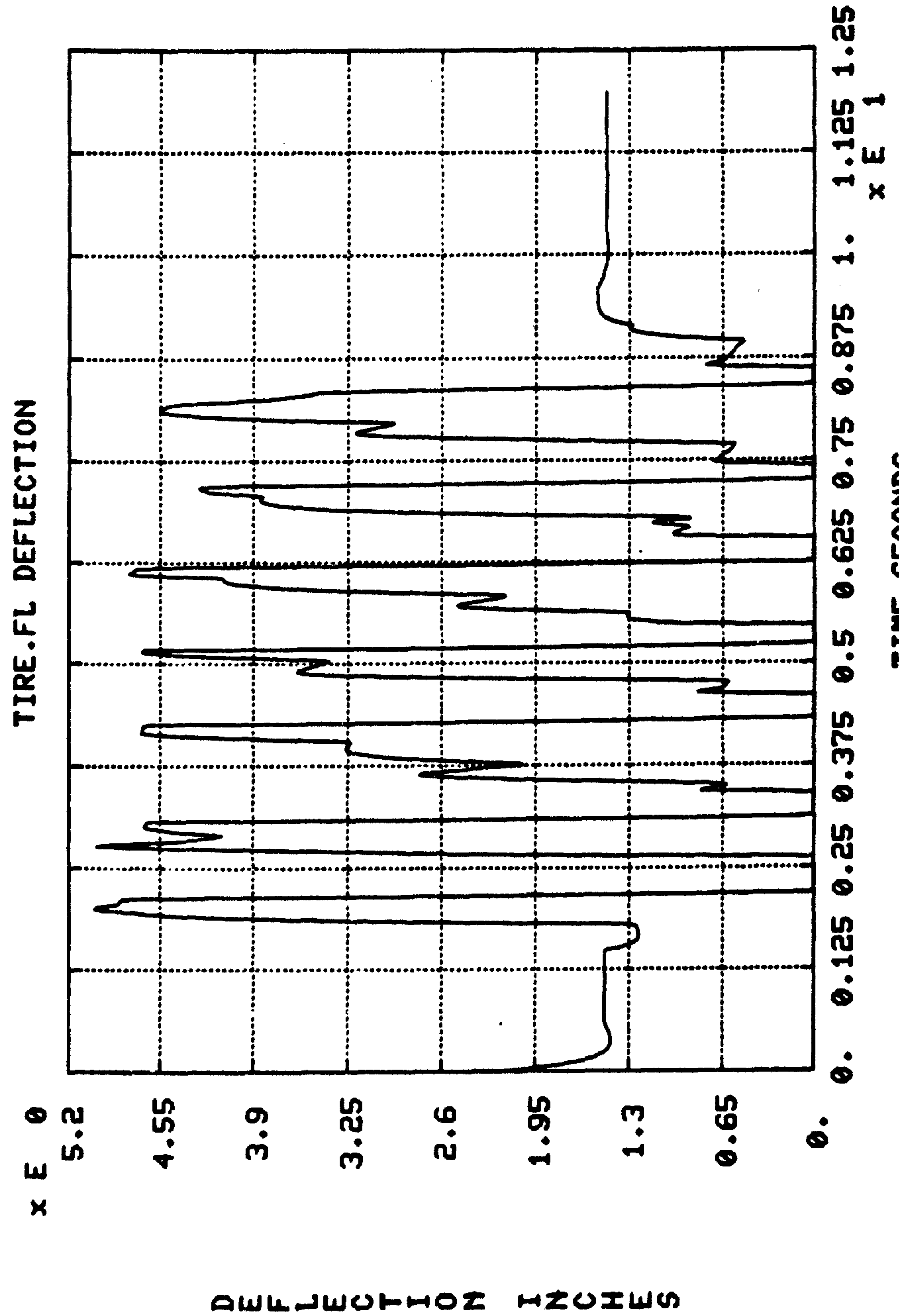


Figure 5-48. Front Left Tire Deflection

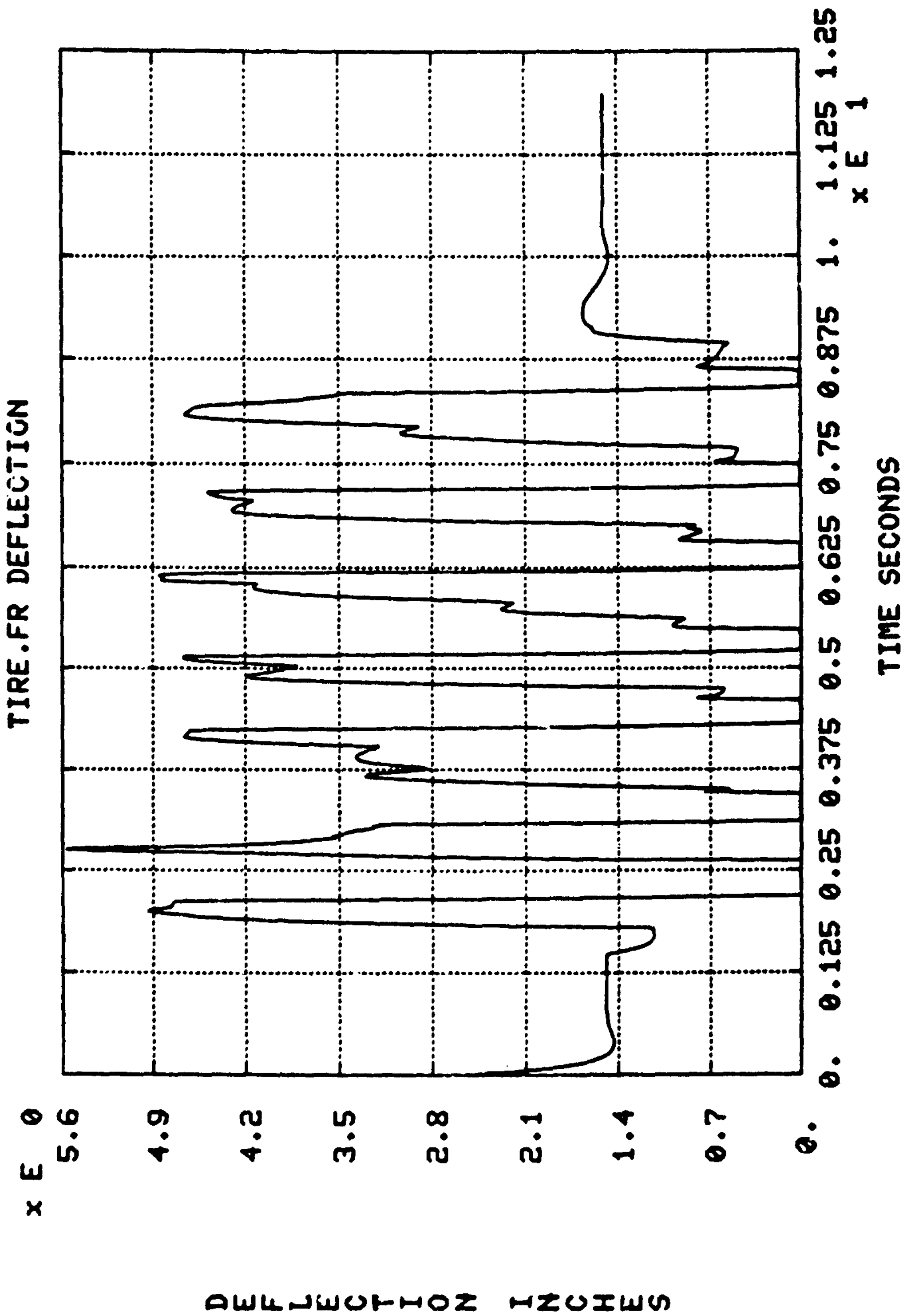


Figure 5-49. Front Right Tire Deflection

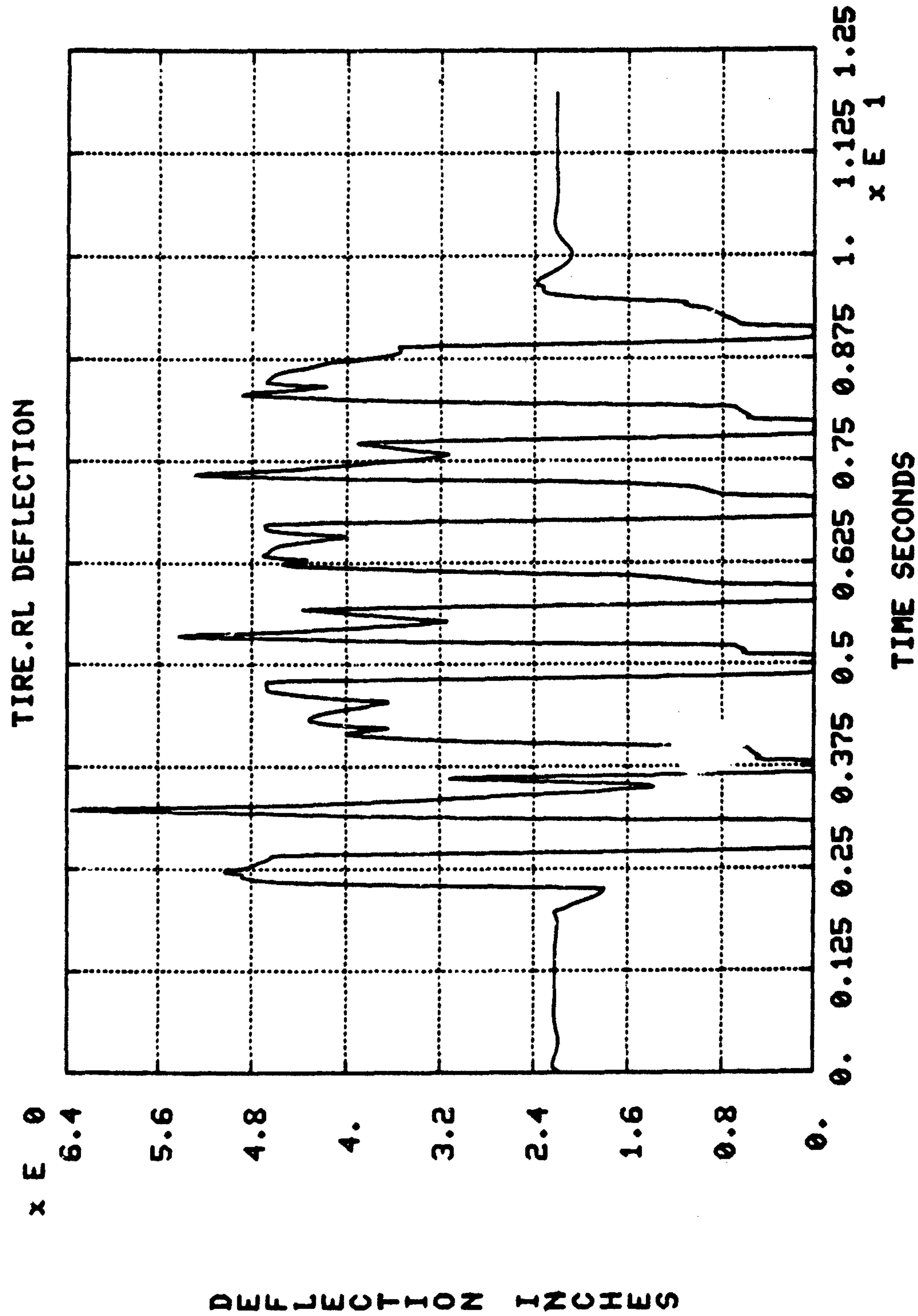


Figure 5-50. Rear Left Tire Deflection

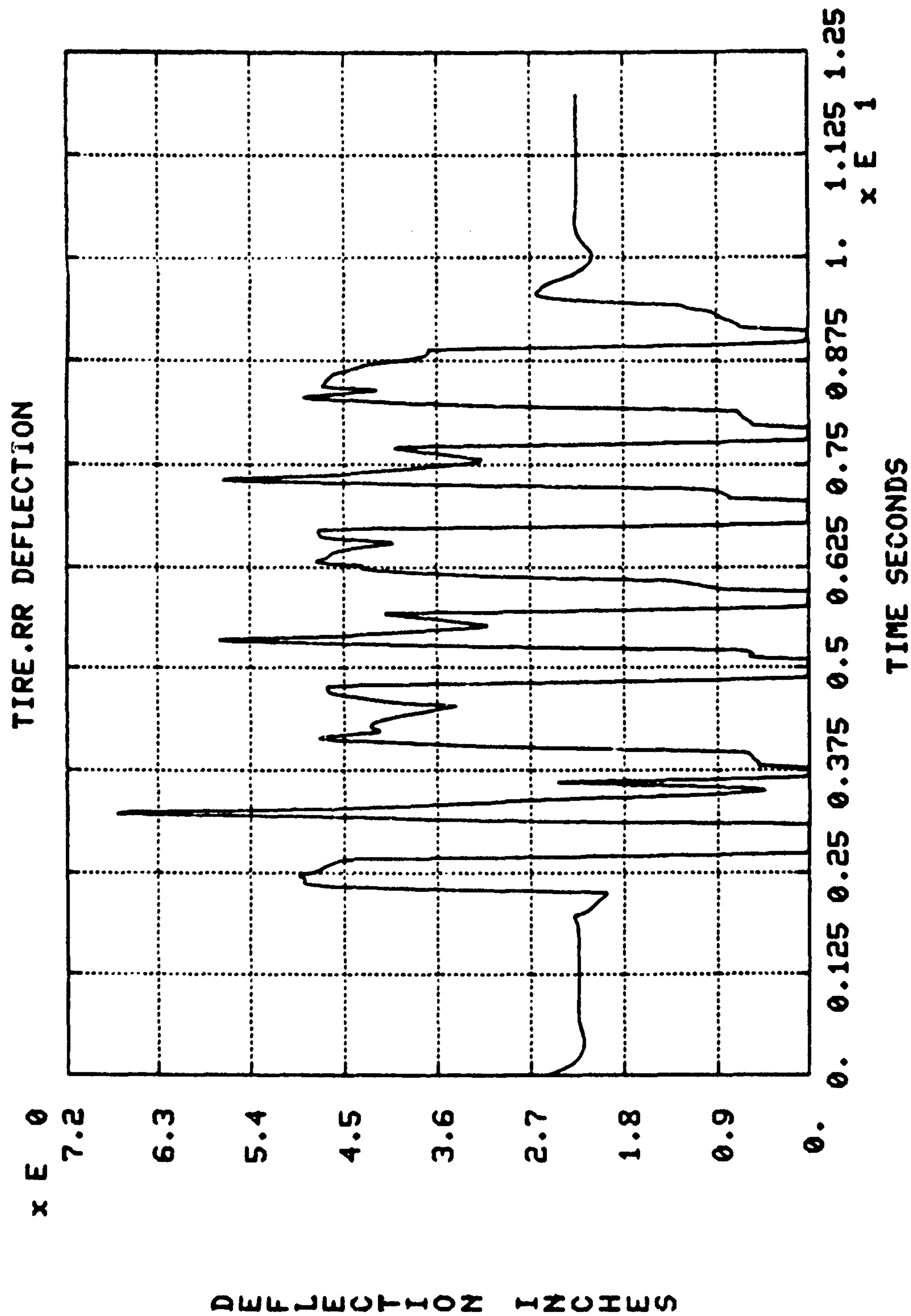


Figure 5-51. Rear Right Tire Deflection

deflection the wheel is off the ground. The front wheels and the rear wheels come off the ground after clearing each of the seven obstacles.

The radius of the run-flat device is 12.50 inches. The free radius of the tire is 18.15 inches. Assuming that the tire rubber thickness is 1.00 inches, if tire deflections exceed 4.65 inches then the inside of the tire has made contact with the run-flat device. The tolerance on the deflection is assumed to be plus or minus one-sixteenth of an inch. The run-flat device is modeled as a linear stiff spring element.

Figures 5-52 through 5-55 show the force generated when the tire makes contact with the run-flat device. The first and second occurrences of contacting the run-flat devices with the front and rear tires occur as the wheels strike the frist obstacle and as the wheels return to the ground and strike the second obstacle.

Figures 5-56 through 5-59 show the total force generated by the tire. This includes tire stiffness, tire damping, and run-flat forces.

Figures 5-60 through 5-63 show the slip angles for the front left, the front right, the rear left, and the rear right tires.

Figures 5-64 through 5-67 show the lateral force on each tire. Lateral force is a function of slip angle and vertical tire force.

Figures 5-68 through 5-83 show the tensile and shear forces acting in each upper and lower ball joint. Tensile forces act along the kingpin axis. The kingpin axis is the line between the upper and lower ball joints. Shear force is the magnitude of the forces perpendicular to the kingpin axis acting at the center of the ball.

For a ductile material, such as steel, the maximum shear stress theory can be used to predict yielding. Joseph E. Shigley states in his book "Mechanical Engineering Design", "this theory predicts that the yield strength in shear is half the yield strength in tension. This theory is conservative and is always on the safe side of test results."[12]

The distortion energy theory can also be used to define the beginning of yield for ductile materials. This theory predicts that the ratio of yield strength in shear to the yield strength in tension is 0.577.[13]

Both theories clearly indicate that for a given ductile material shear forces are more dangerous than tensile forces.

The largest tensile and shear force occur within the lower rear right ball joint when the right rear wheel strikes the ground after clearing the first obstacle. At this time the right rear shock makes metal-to-metal contact in compression and the right rear tire makes contact with the run-flat device. These tire and shock absorber forces generate the large tensile and shear forces experienced by the ball joint.

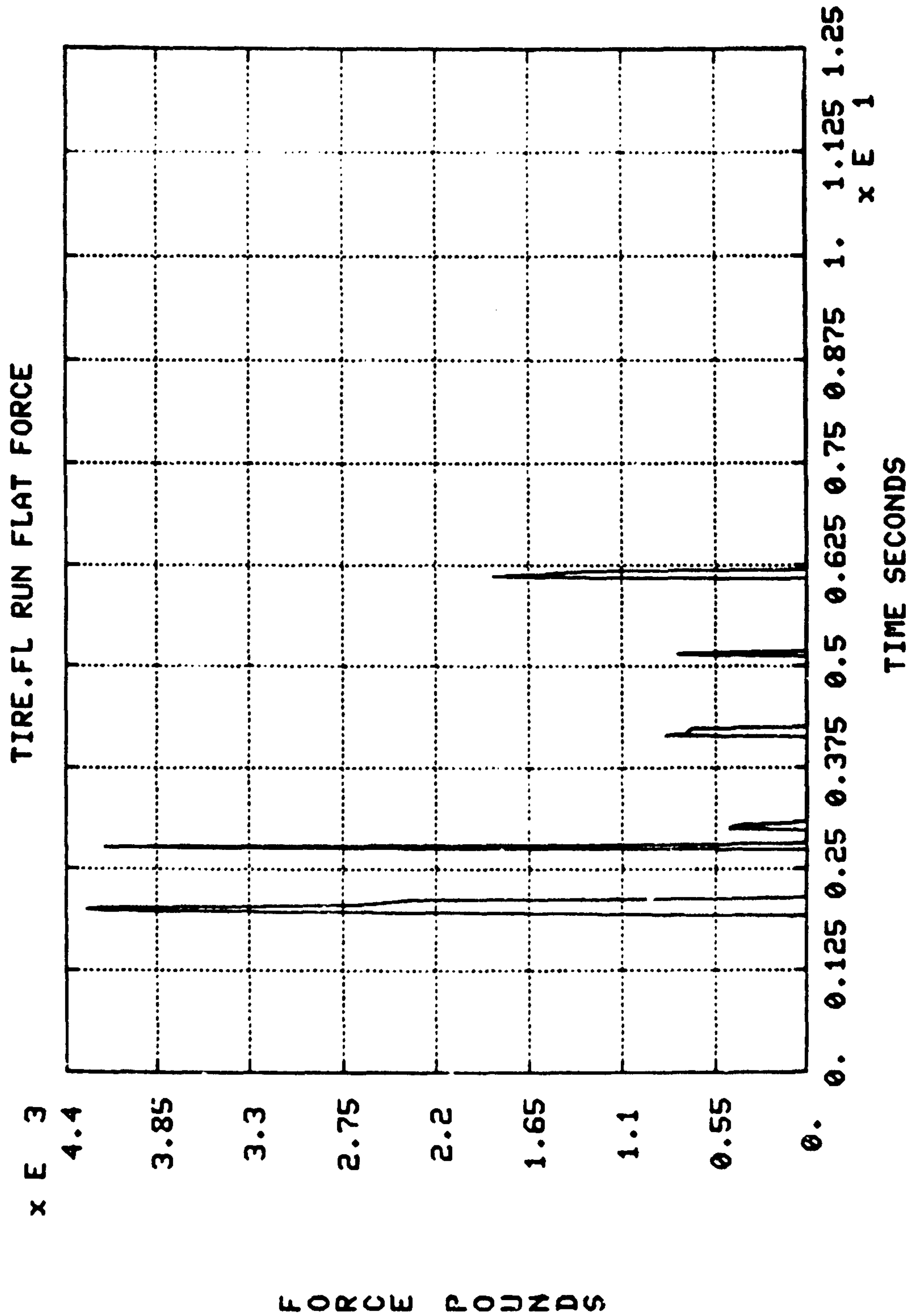


Figure 5-52. Front Left Tire Run Flat Force

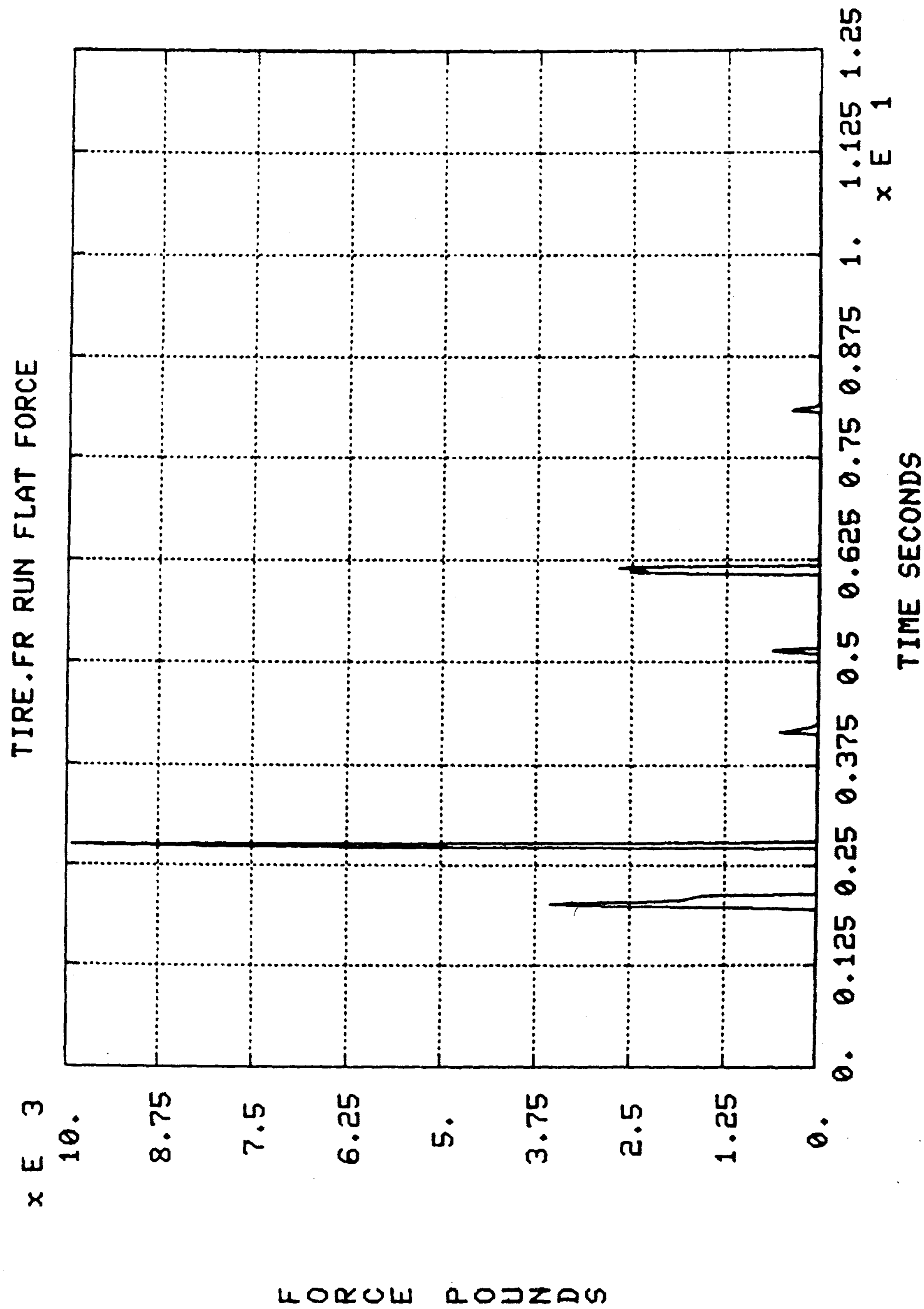


Figure 5-53. Front Right Tire Run Flat Force

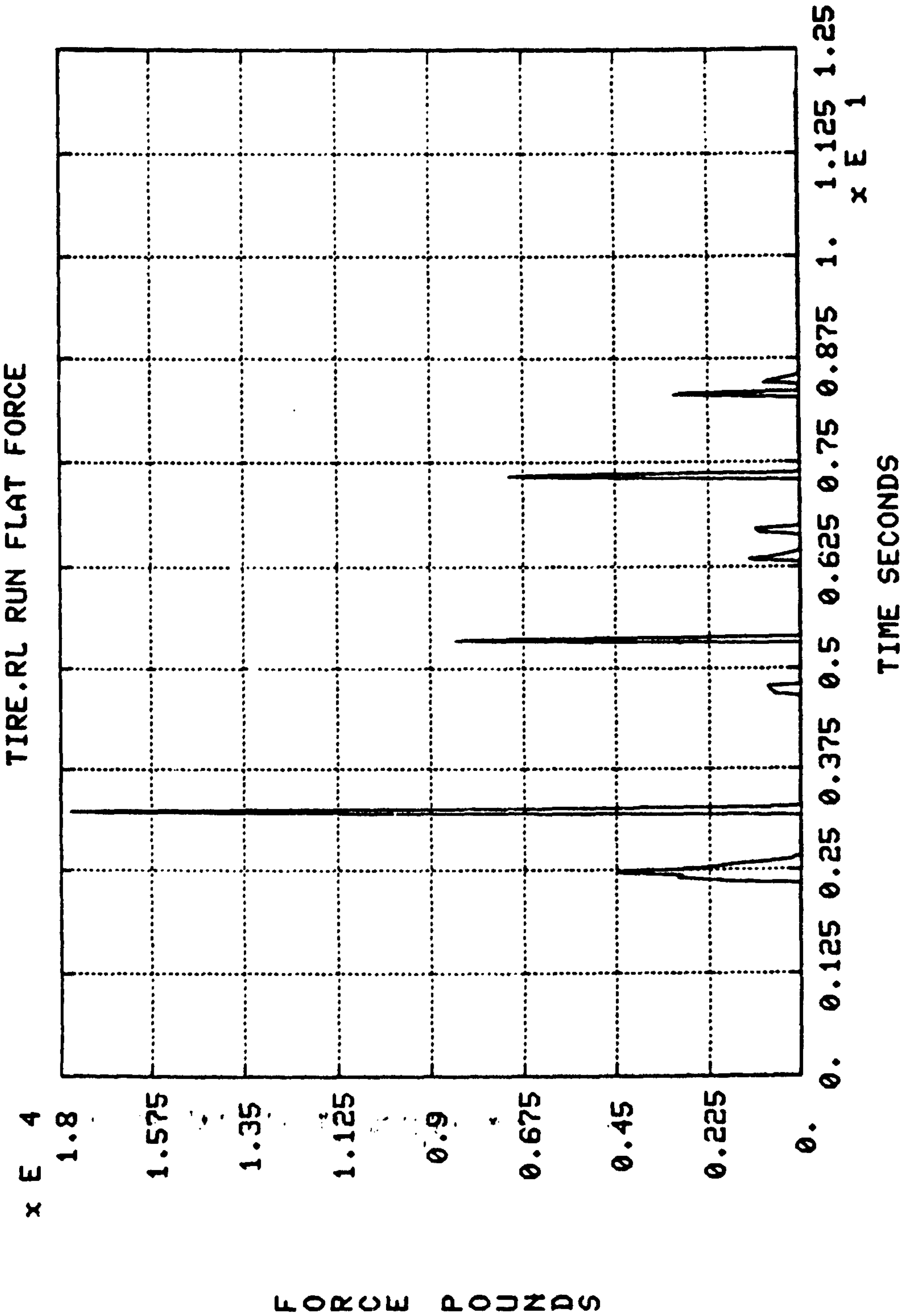


Figure 5-54. Rear Left Tire Run Flat Force

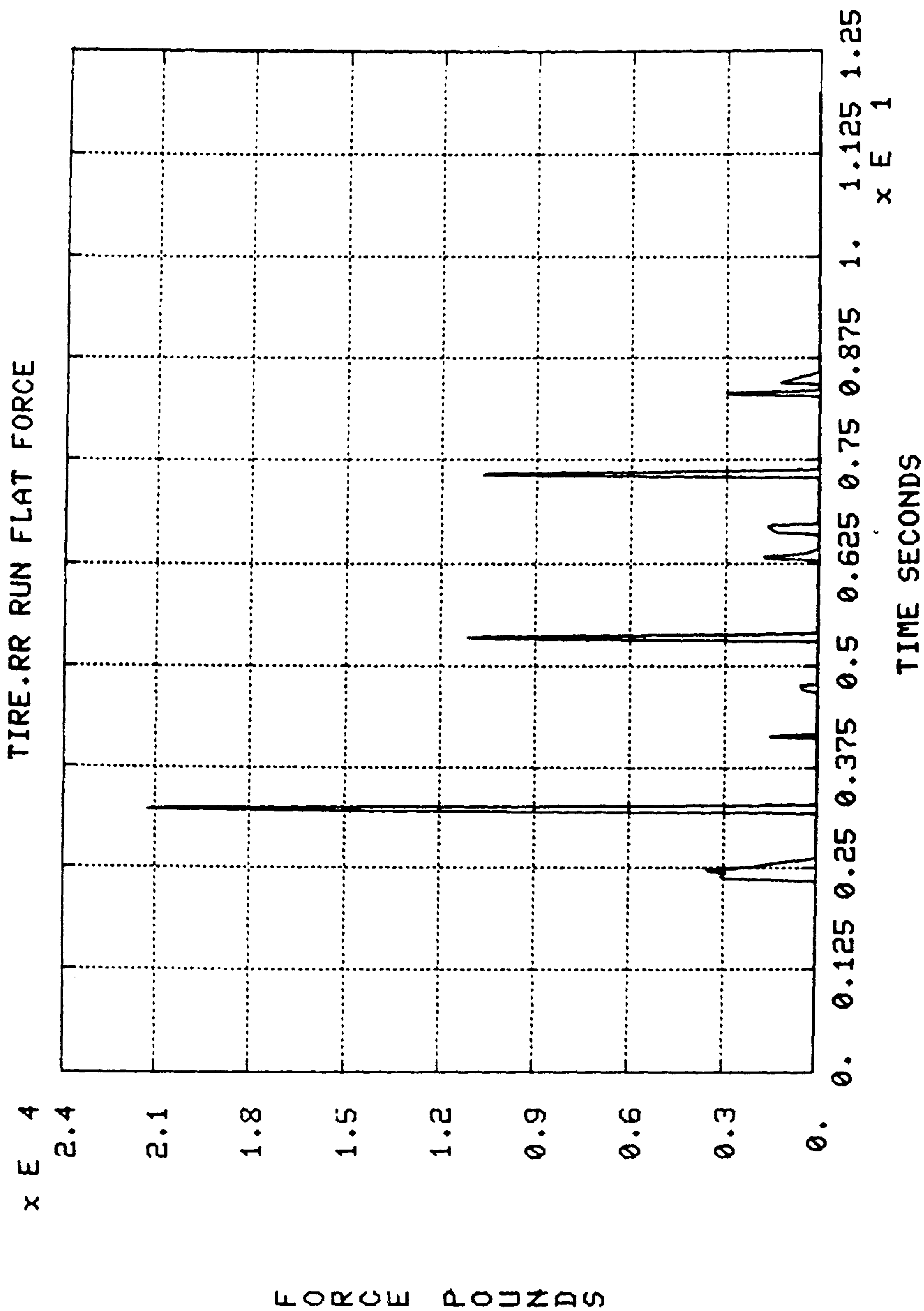


Figure 5-55. Rear Right Tire Run Flat Force

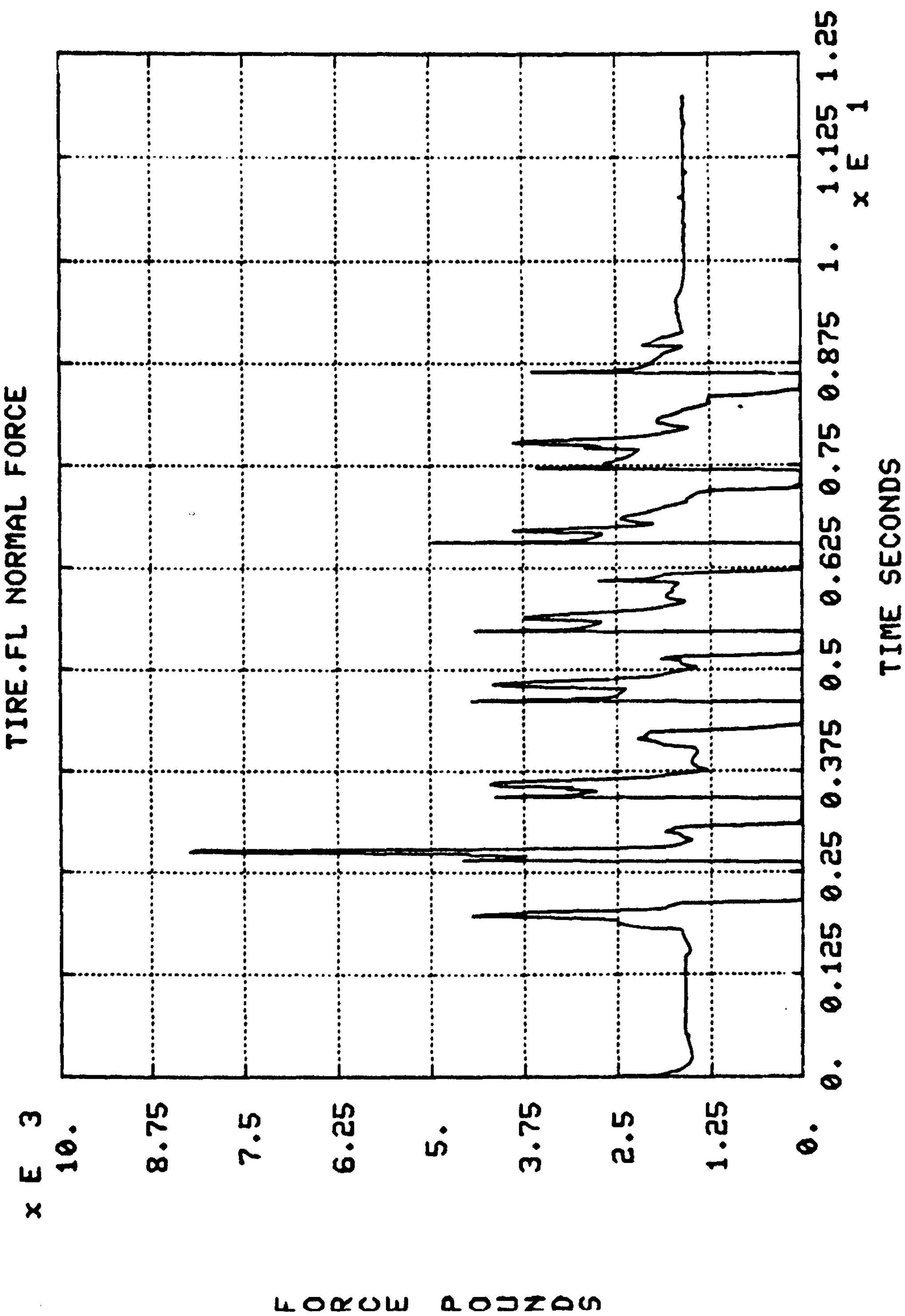


Figure 5-56. Front Left Tire Normal Force

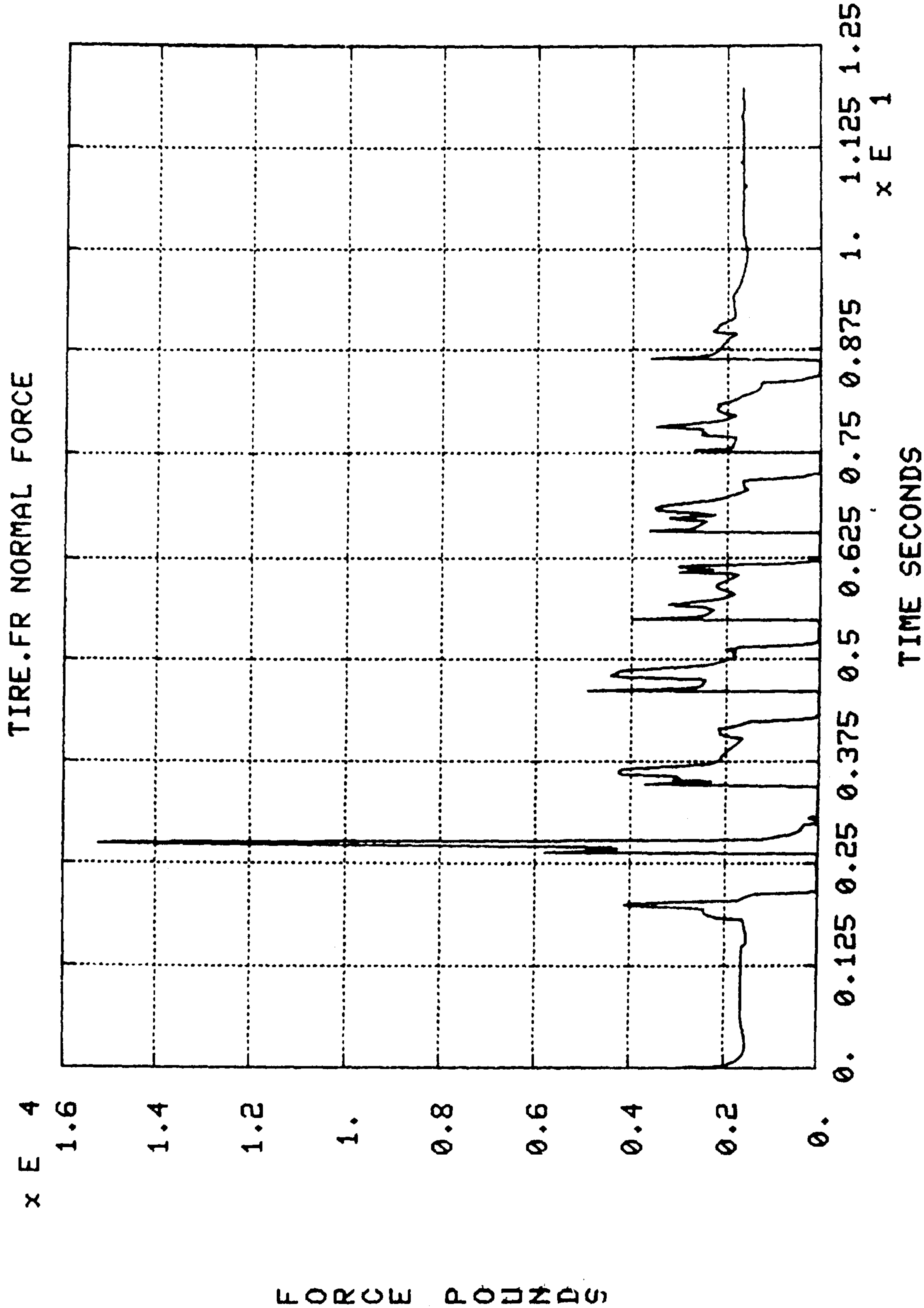


Figure 5-57. Front Right Tire Normal Force

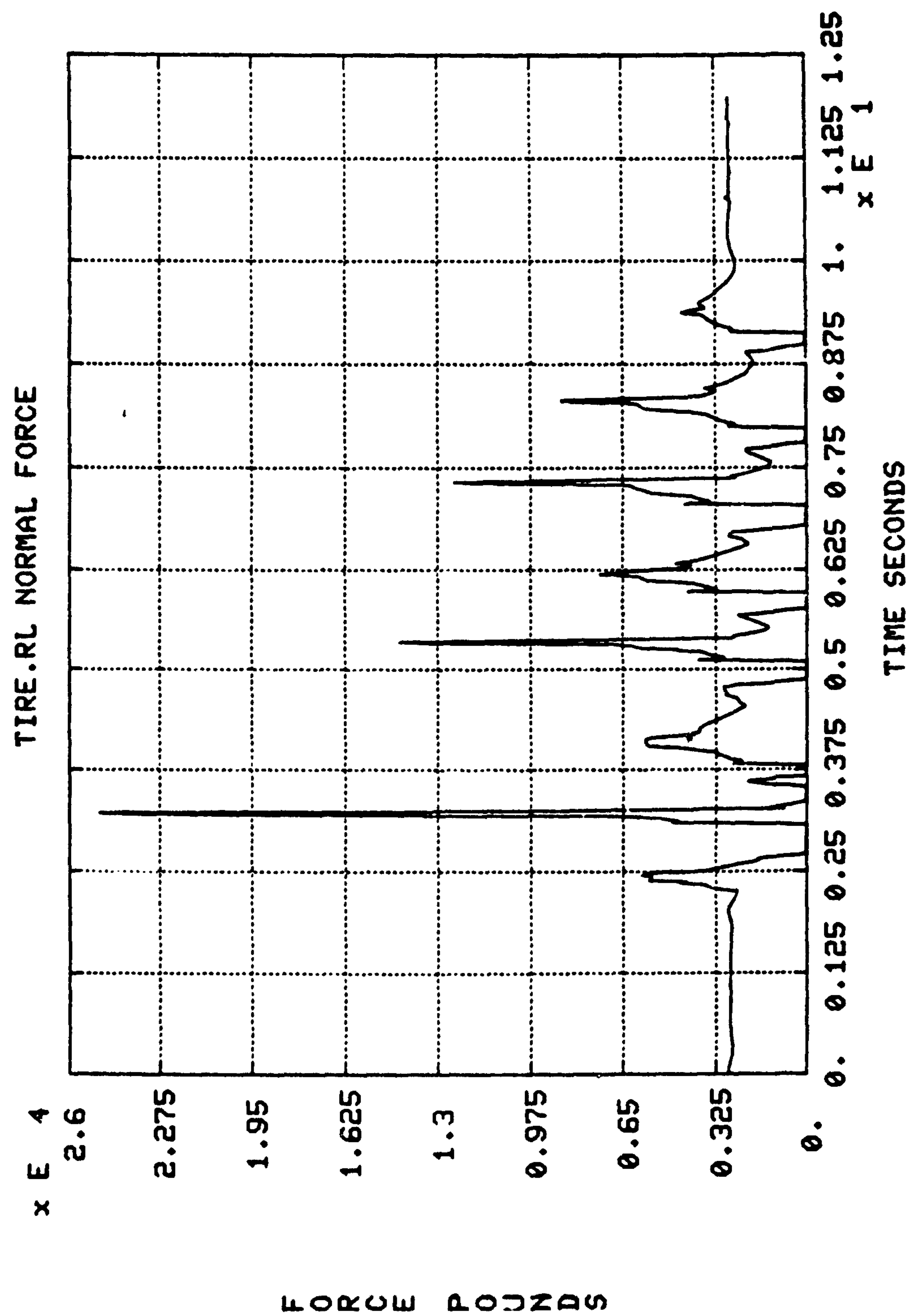


Figure 5-58. Rear Left Tire Normal Force

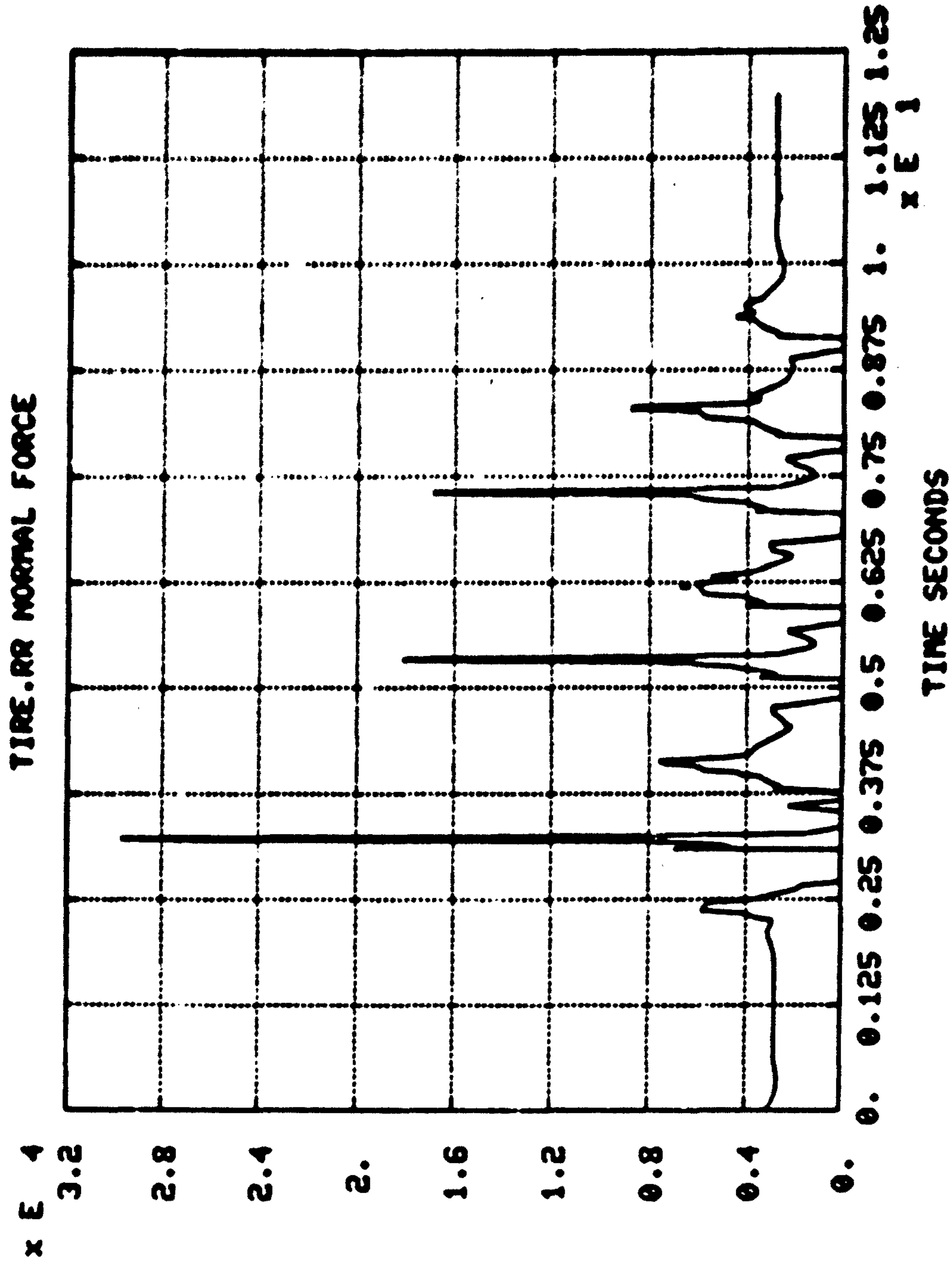


Figure 5-59. Rear Right Tire Normal Force

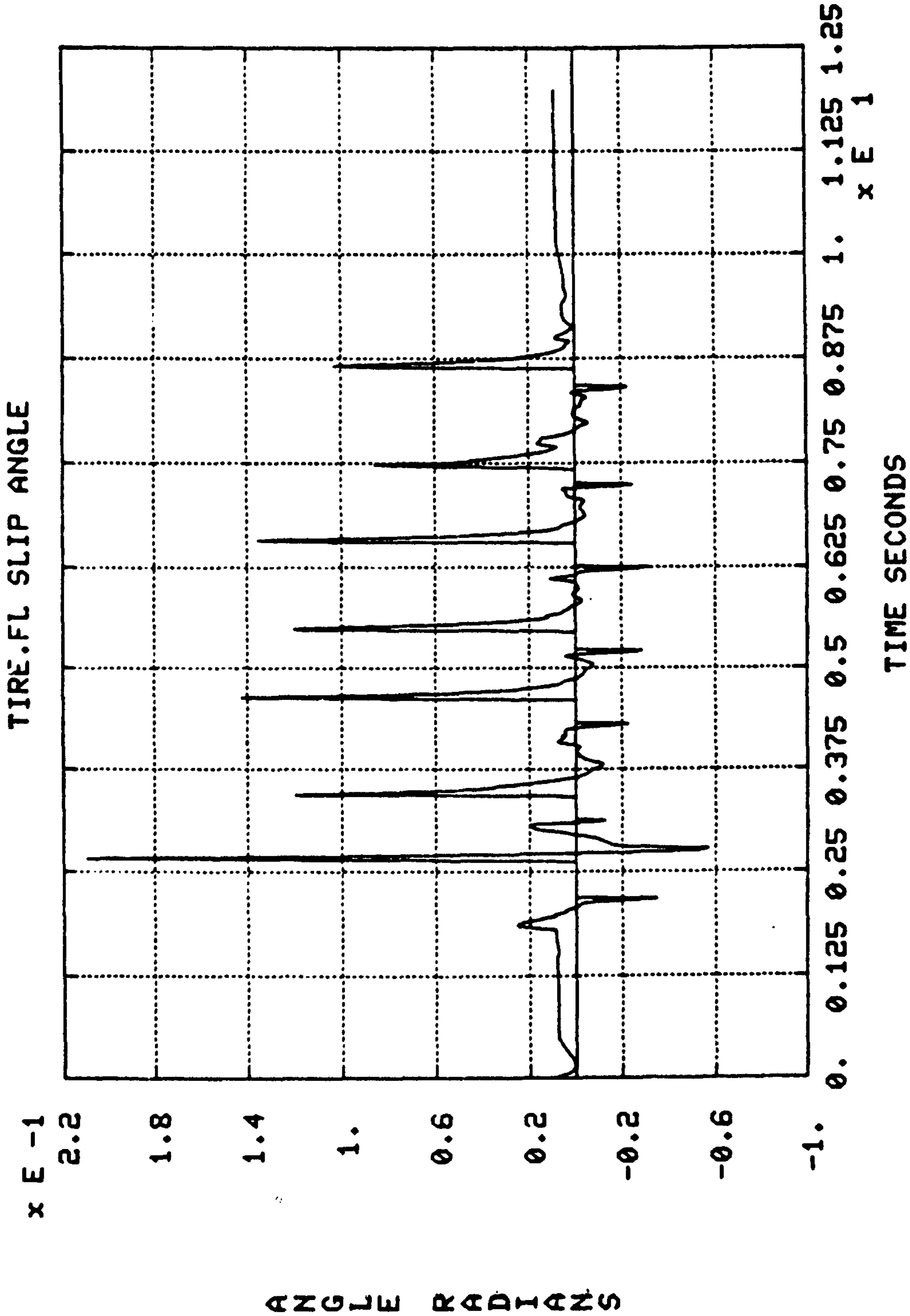


Figure 5-60. Front Left Tire Slip Angle

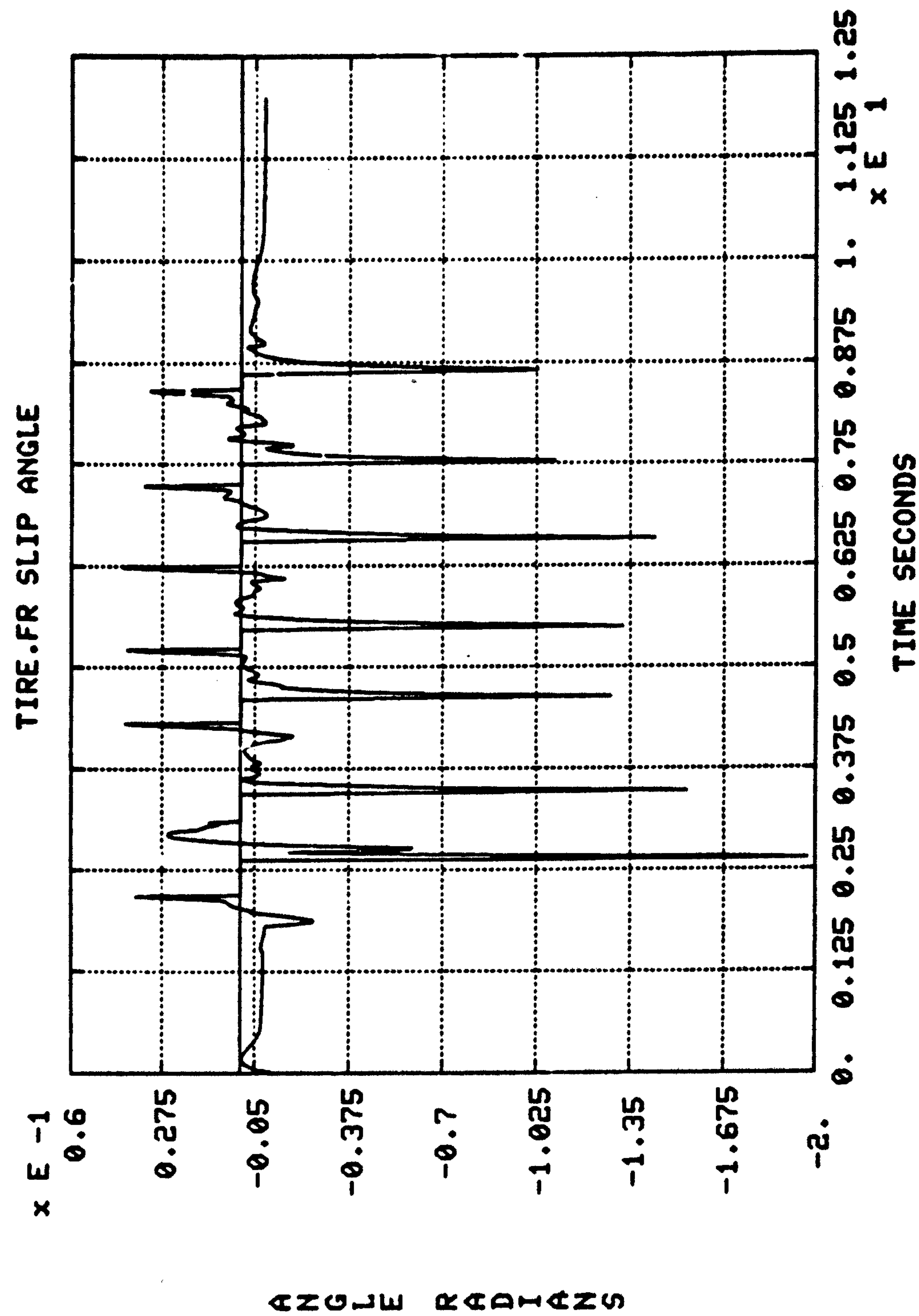


Figure 5-61. Front Right Tire Slip Angle

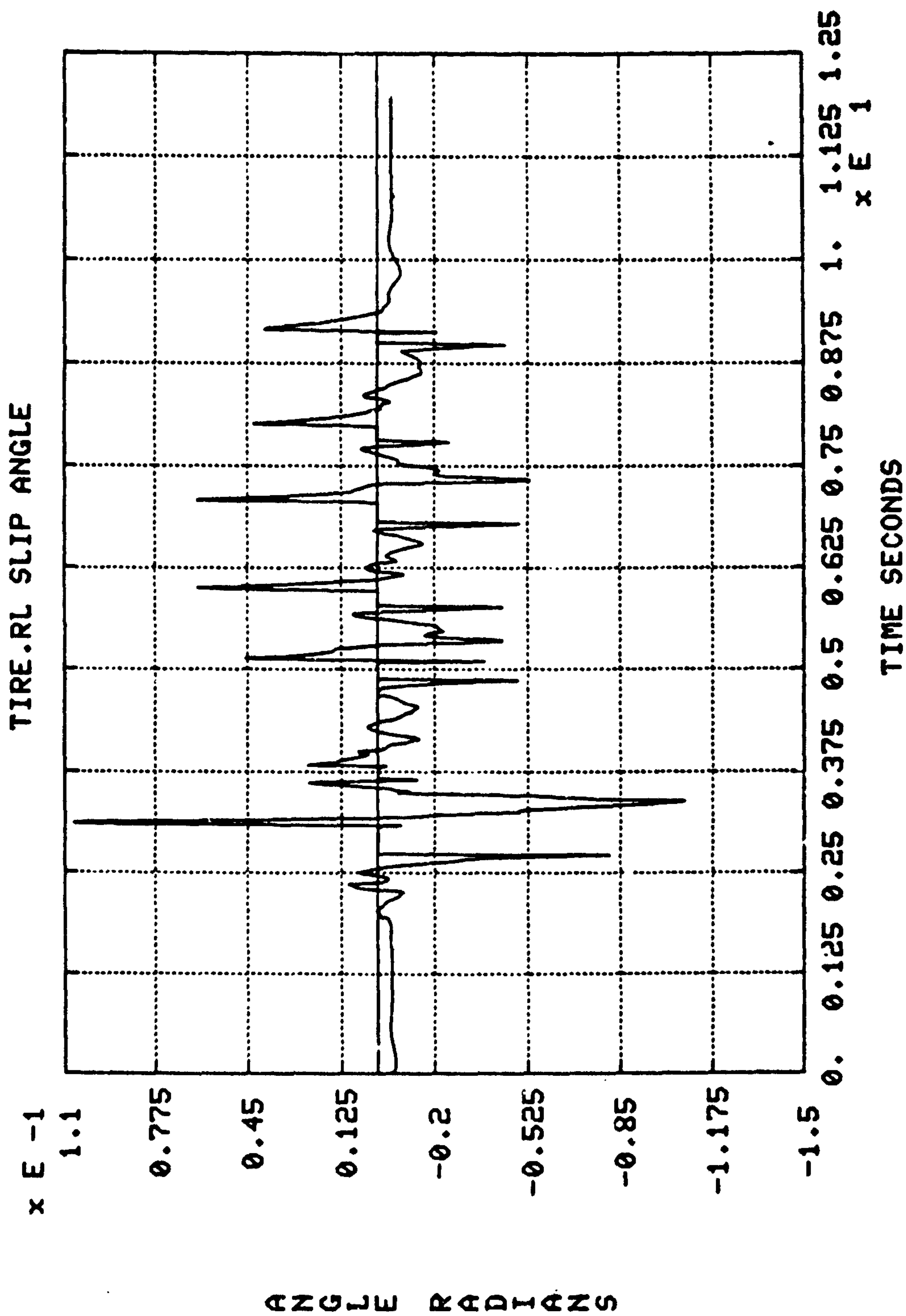


Figure 5-62. Rear Left Tire Slip Angle

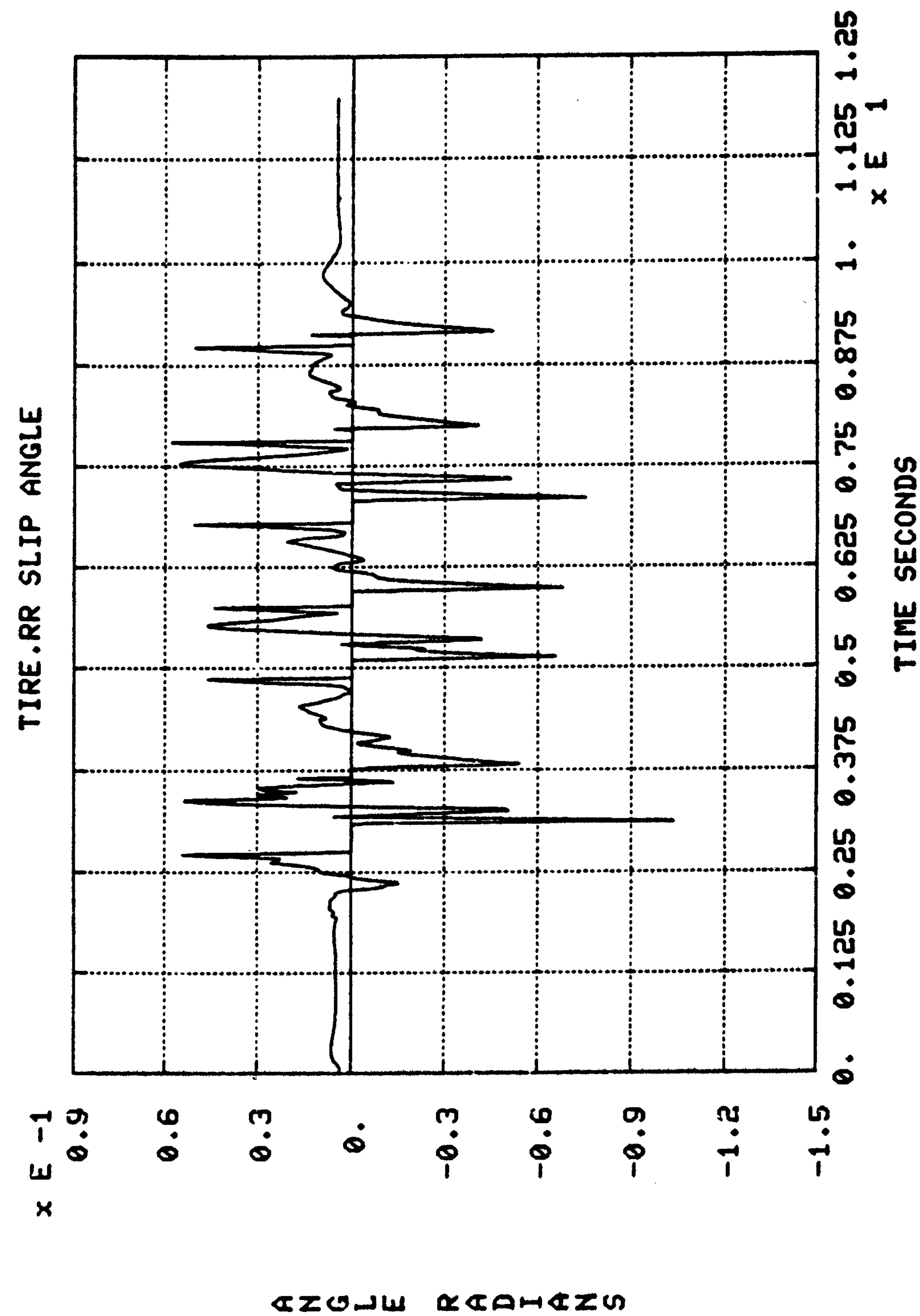


Figure 5-63. Rear Right Tire Slip Angle

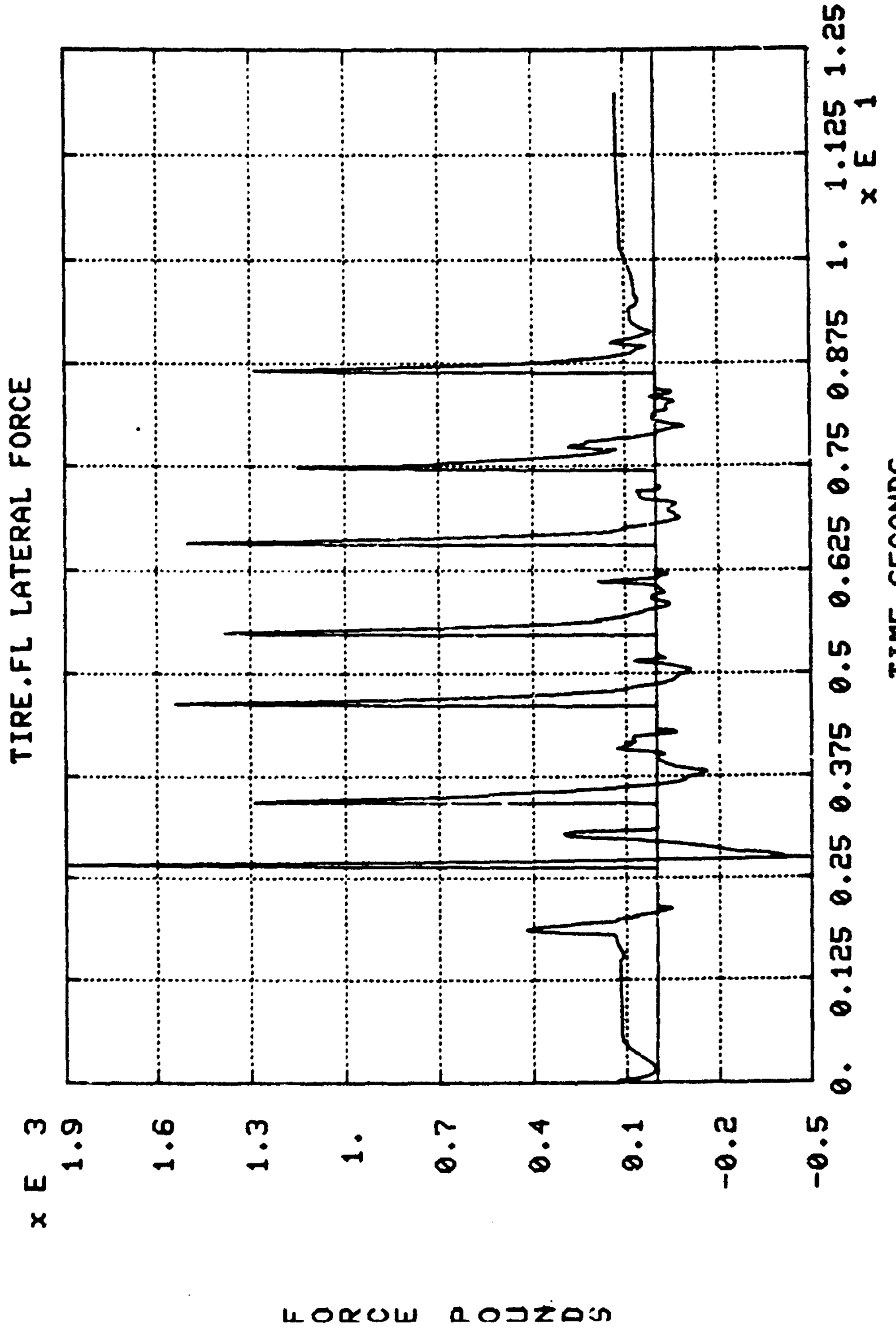


Figure 5-64. Front Left Tire Lateral Force

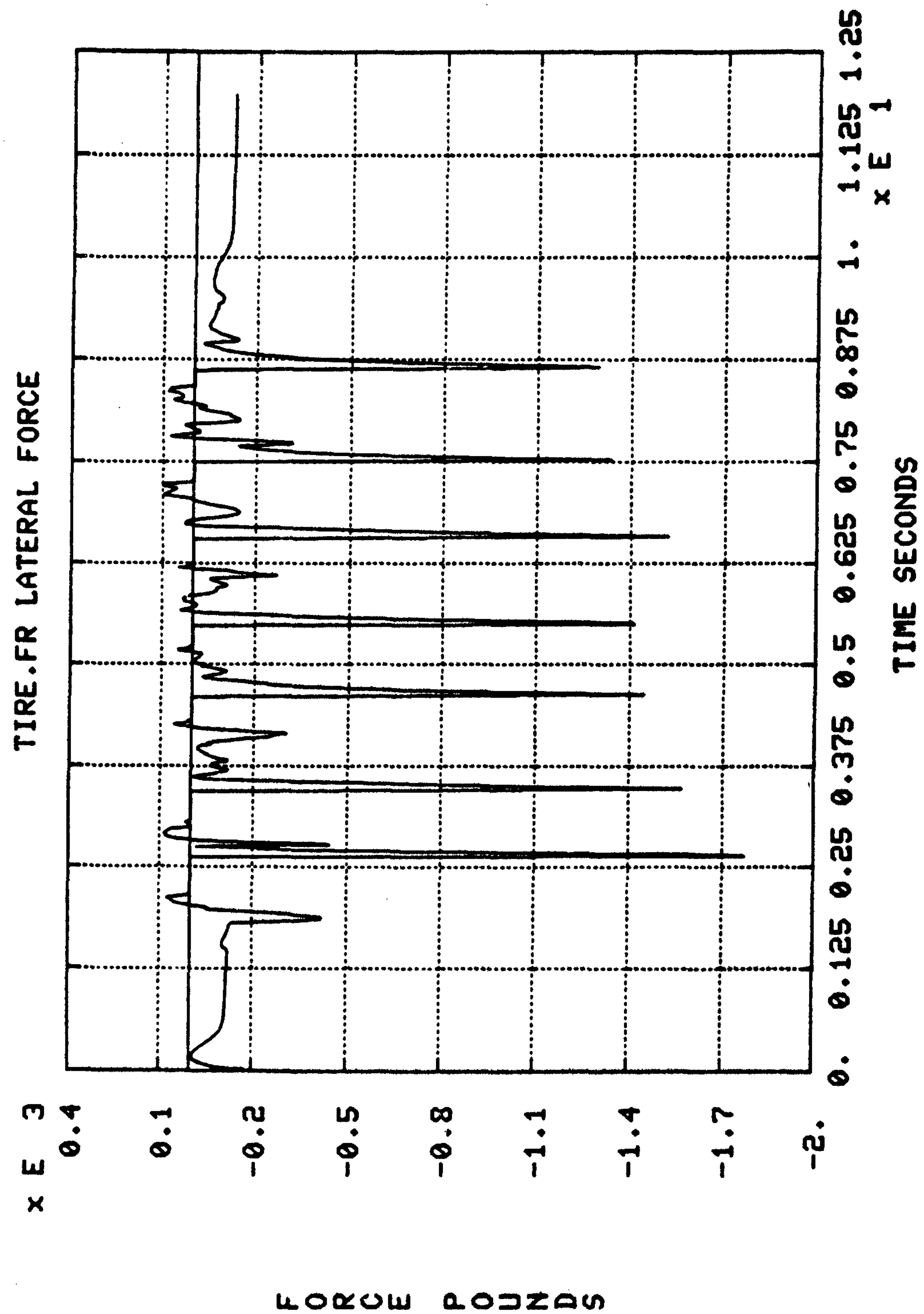


Figure 5-65 Front Right Tire Lateral Force

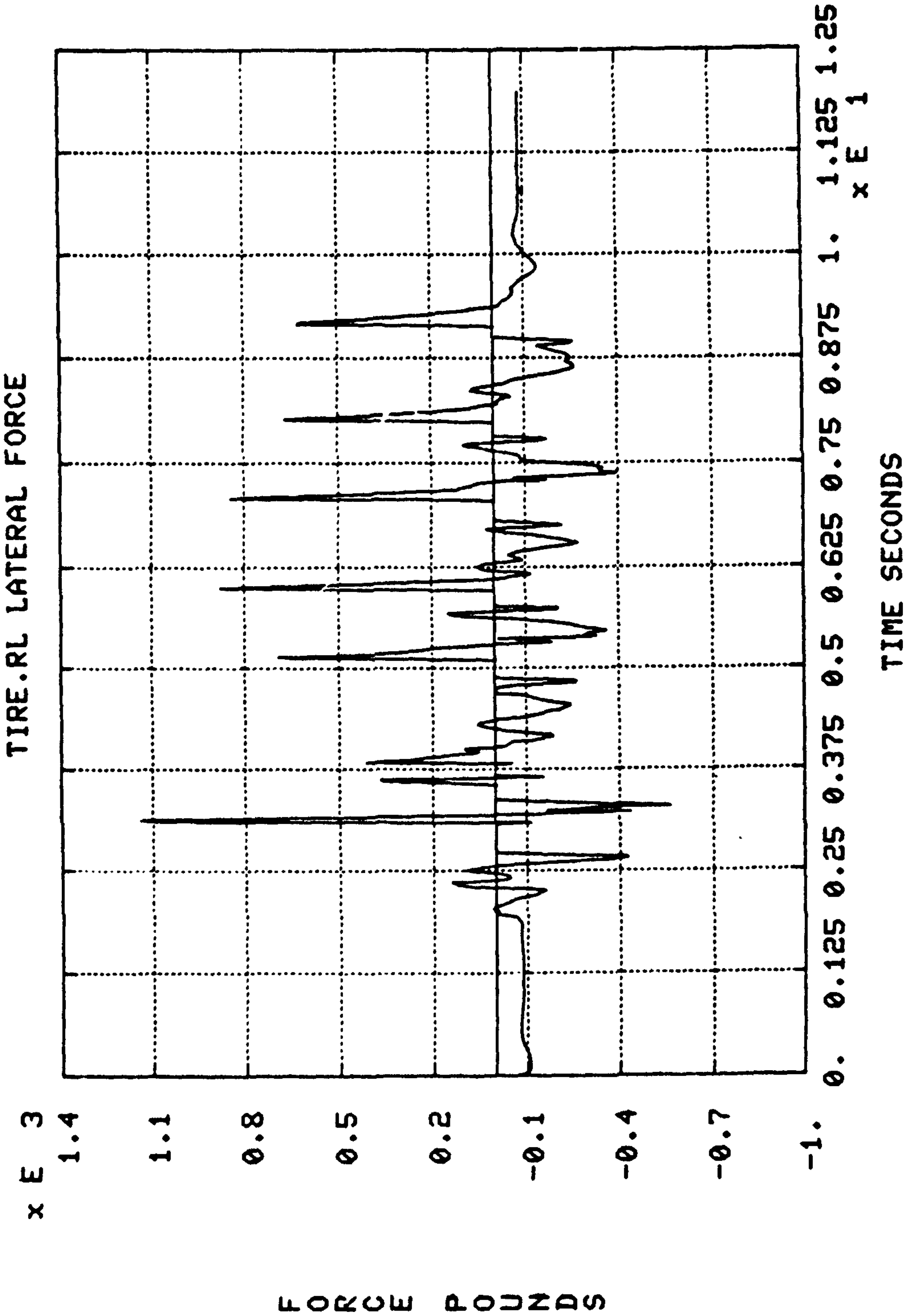


Figure 5-66. Rear Left Tire Lateral Force

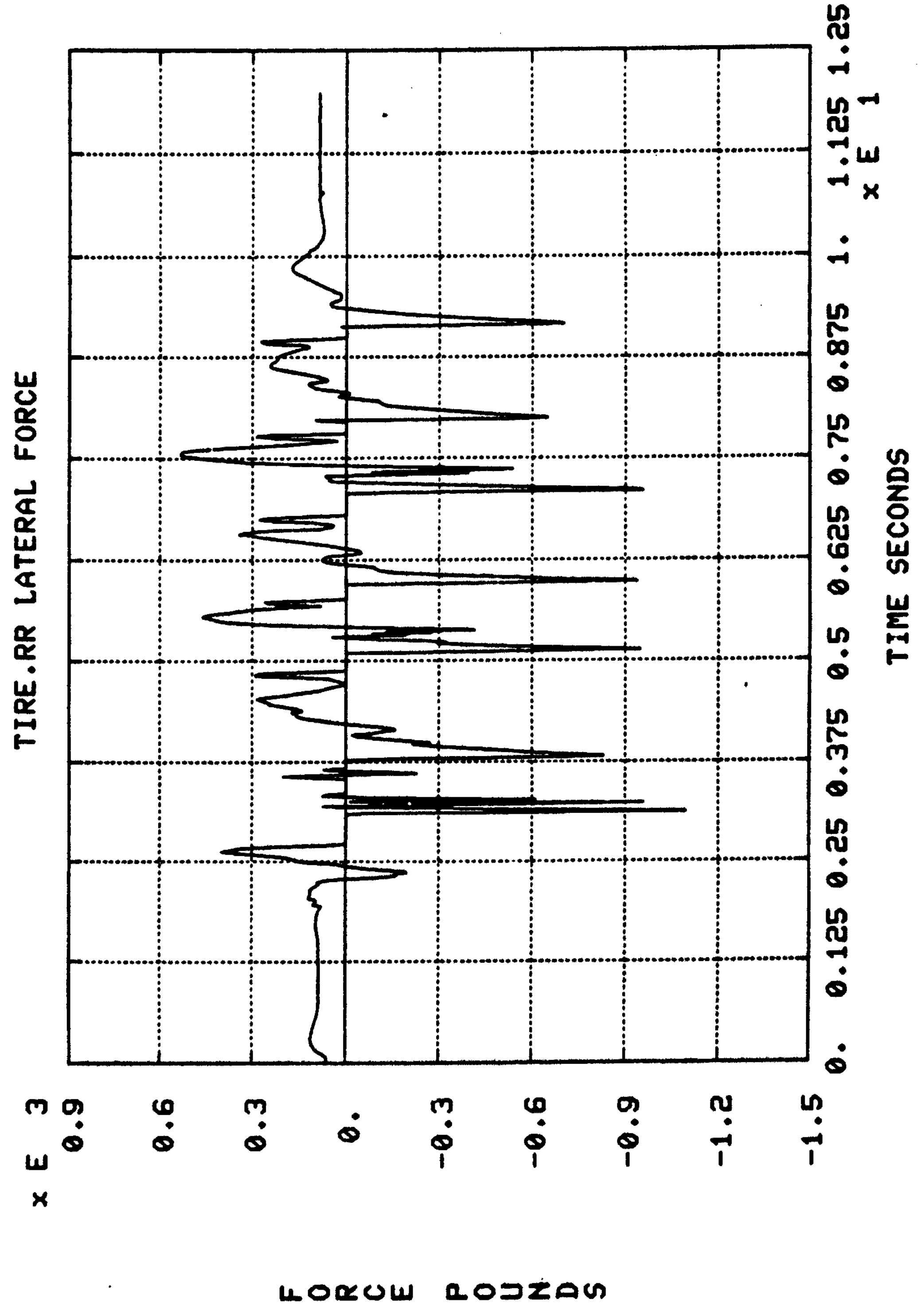


Figure 5-67. Rear Right Tire Lateral Force

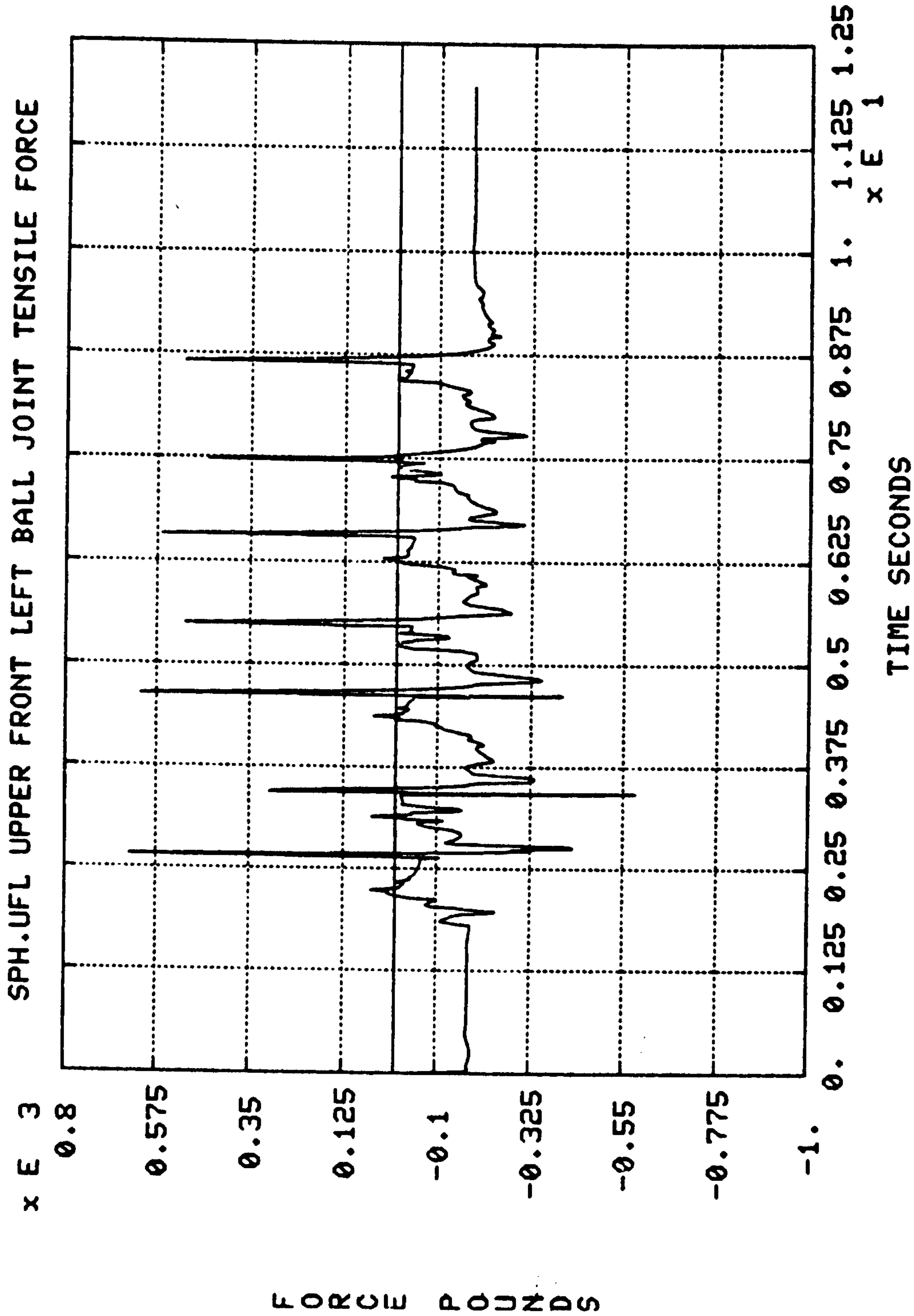


Figure 5-68. Upper Front Left Ball Joint Tensile Force

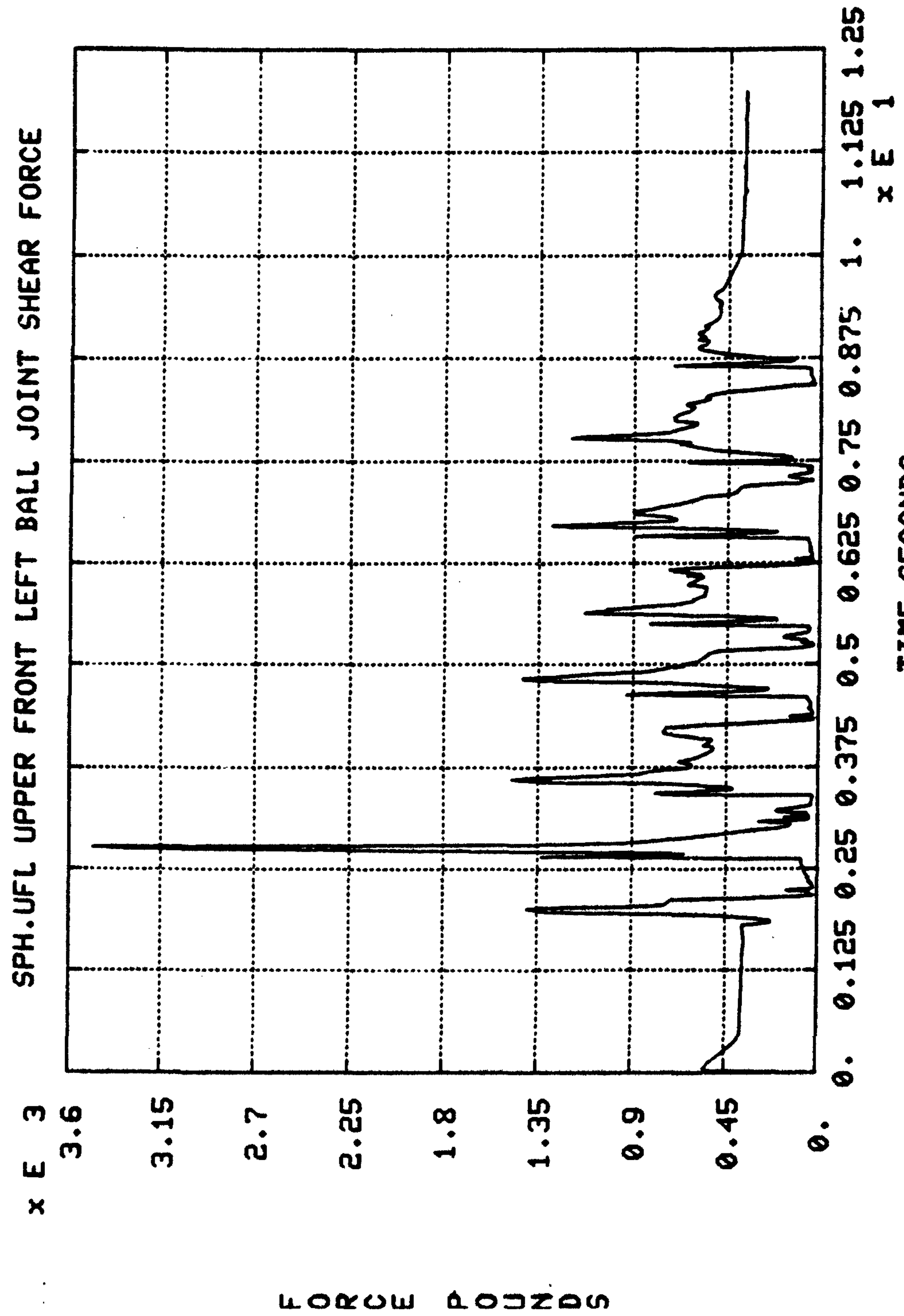


Figure 5-69. Upper Front Left Ball Joint Shear Force

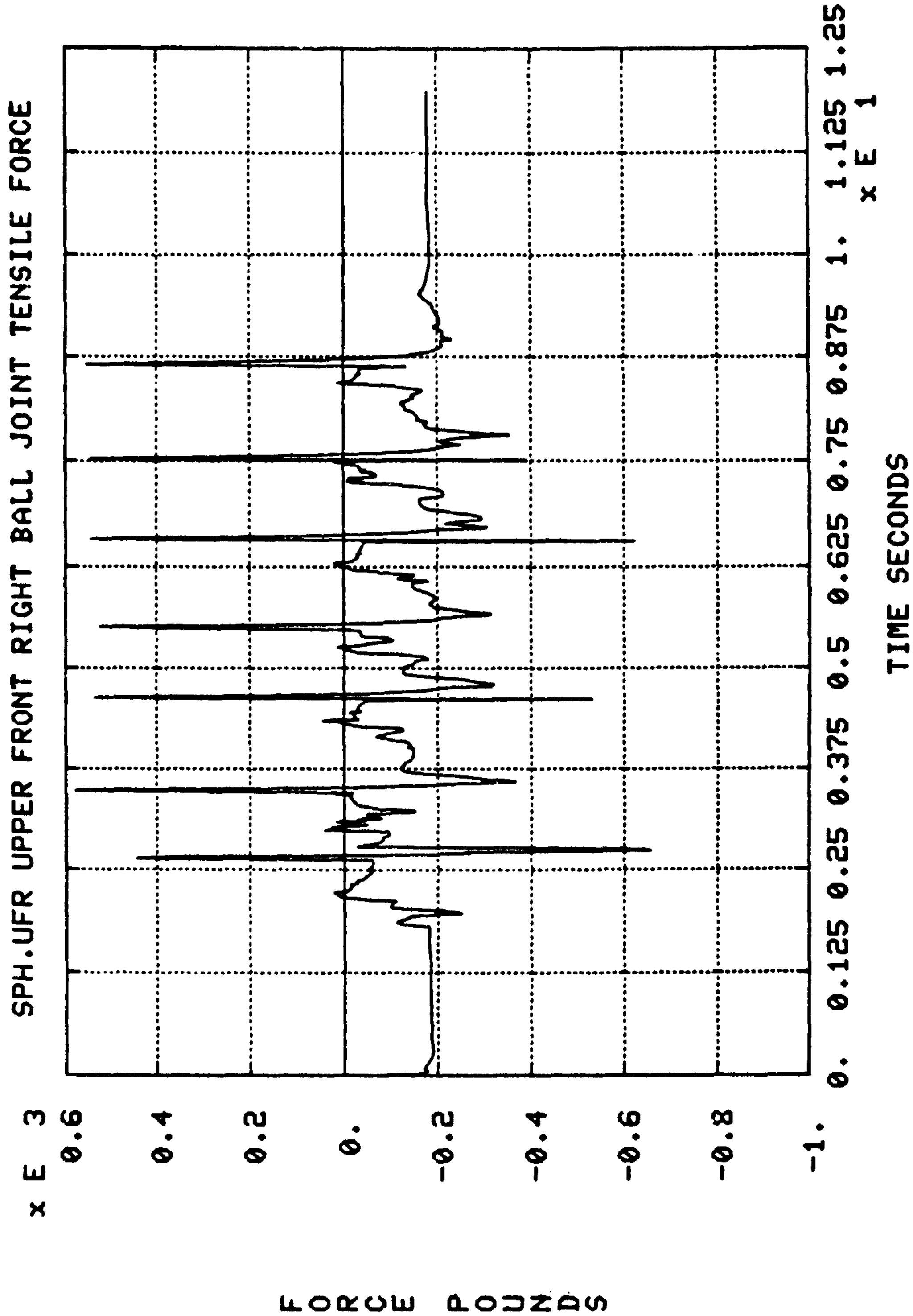


Figure 5-70. Upper Front Right Ball Joint Tensile Force

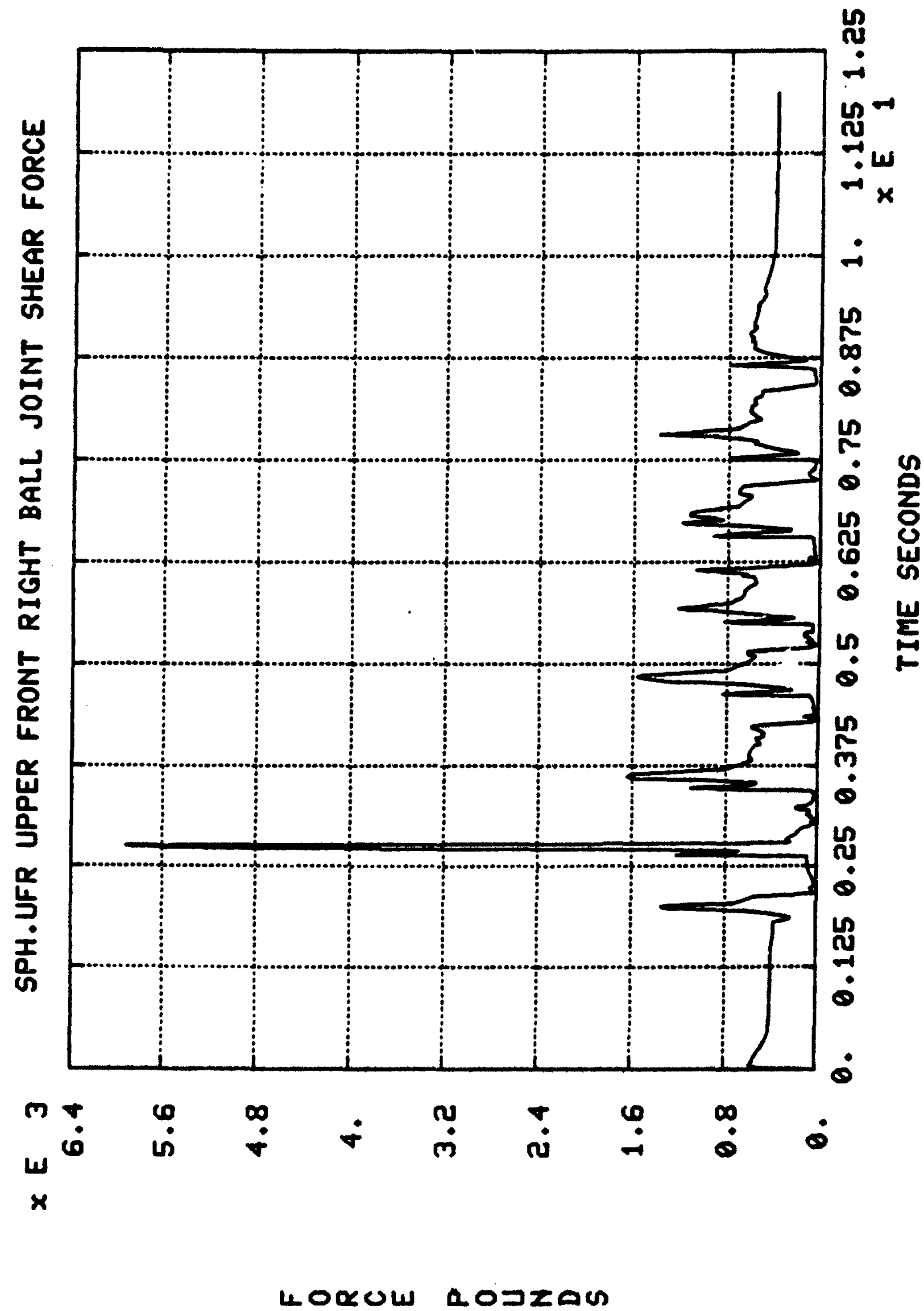


Figure 5-71. Upper Front Right Ball Joint Shear Force

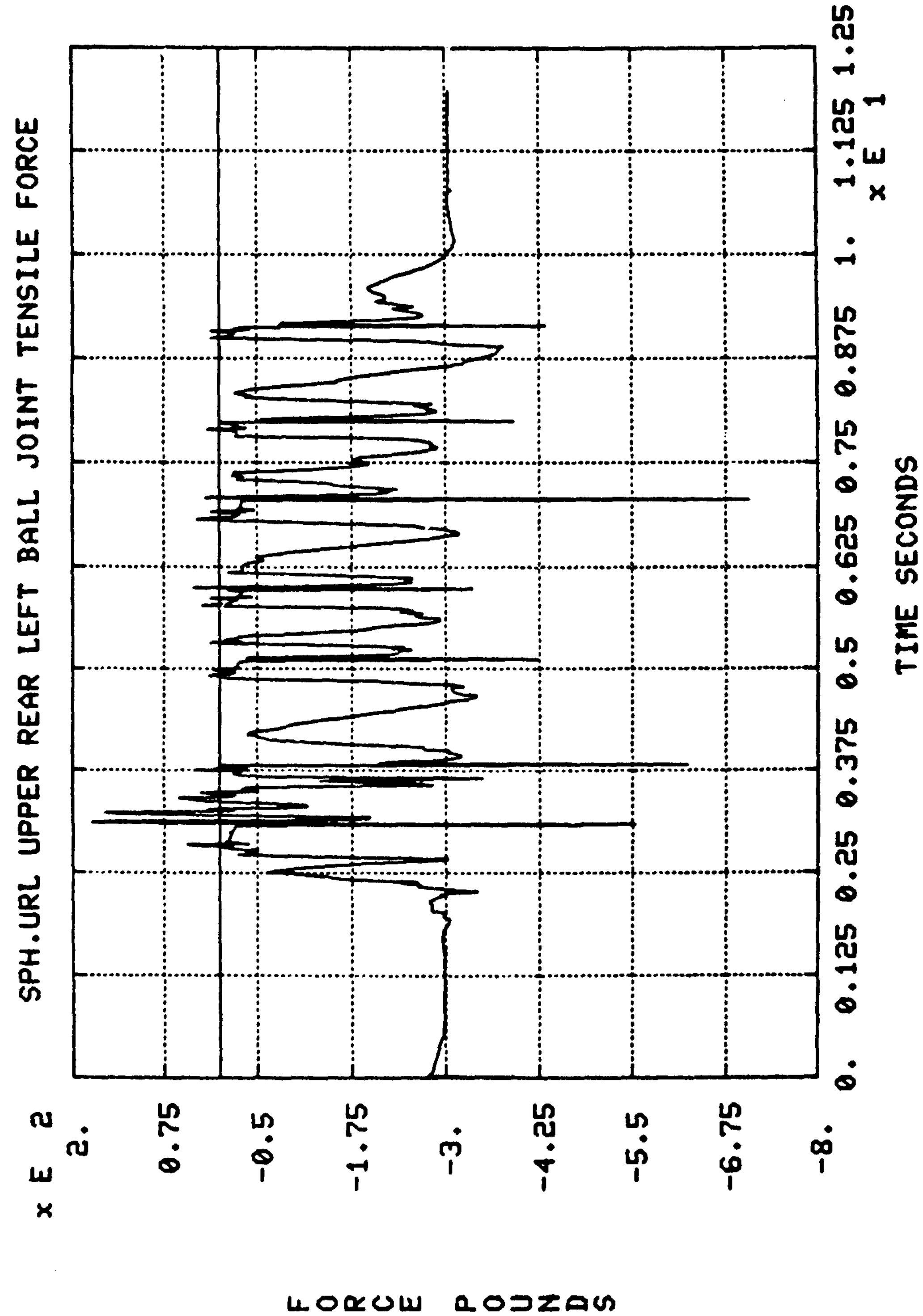


Figure 5-72. Upper Rear Left Ball Joint Tensile Force

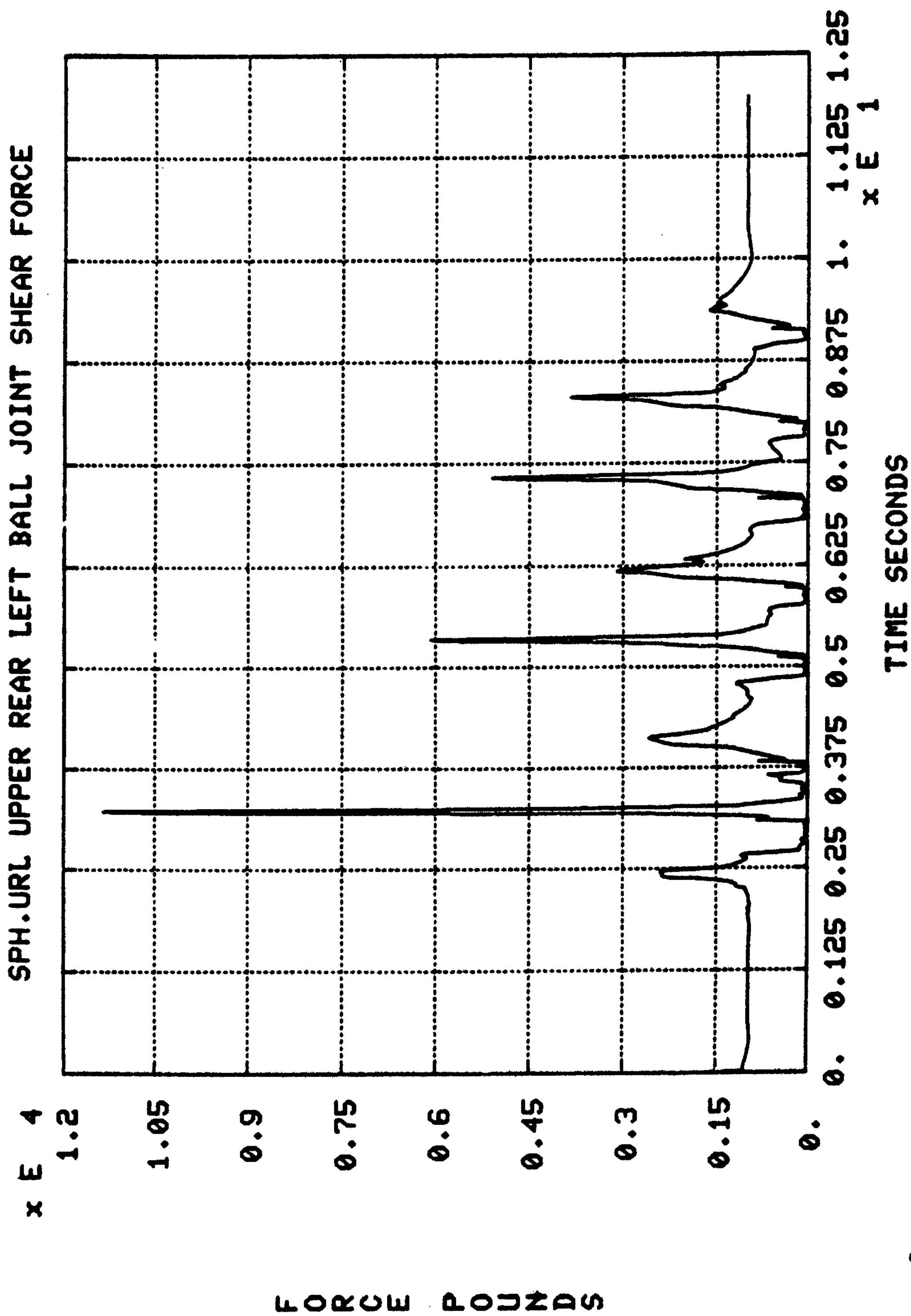


Figure 5-73. Upper Rear Left Ball Joint Shear Force

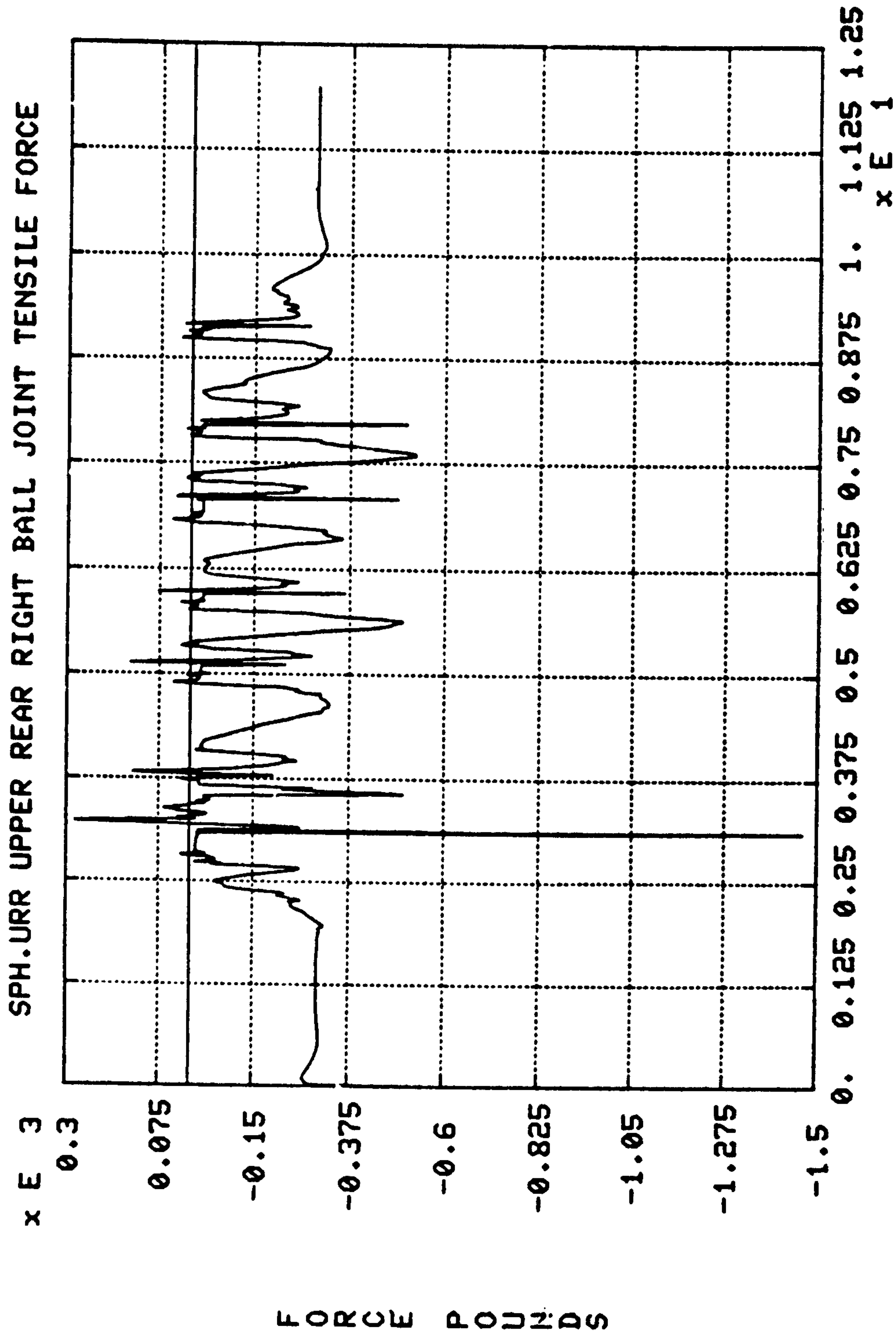


Figure 5-74. Upper Rear Right B.J. Joint Tensile Force

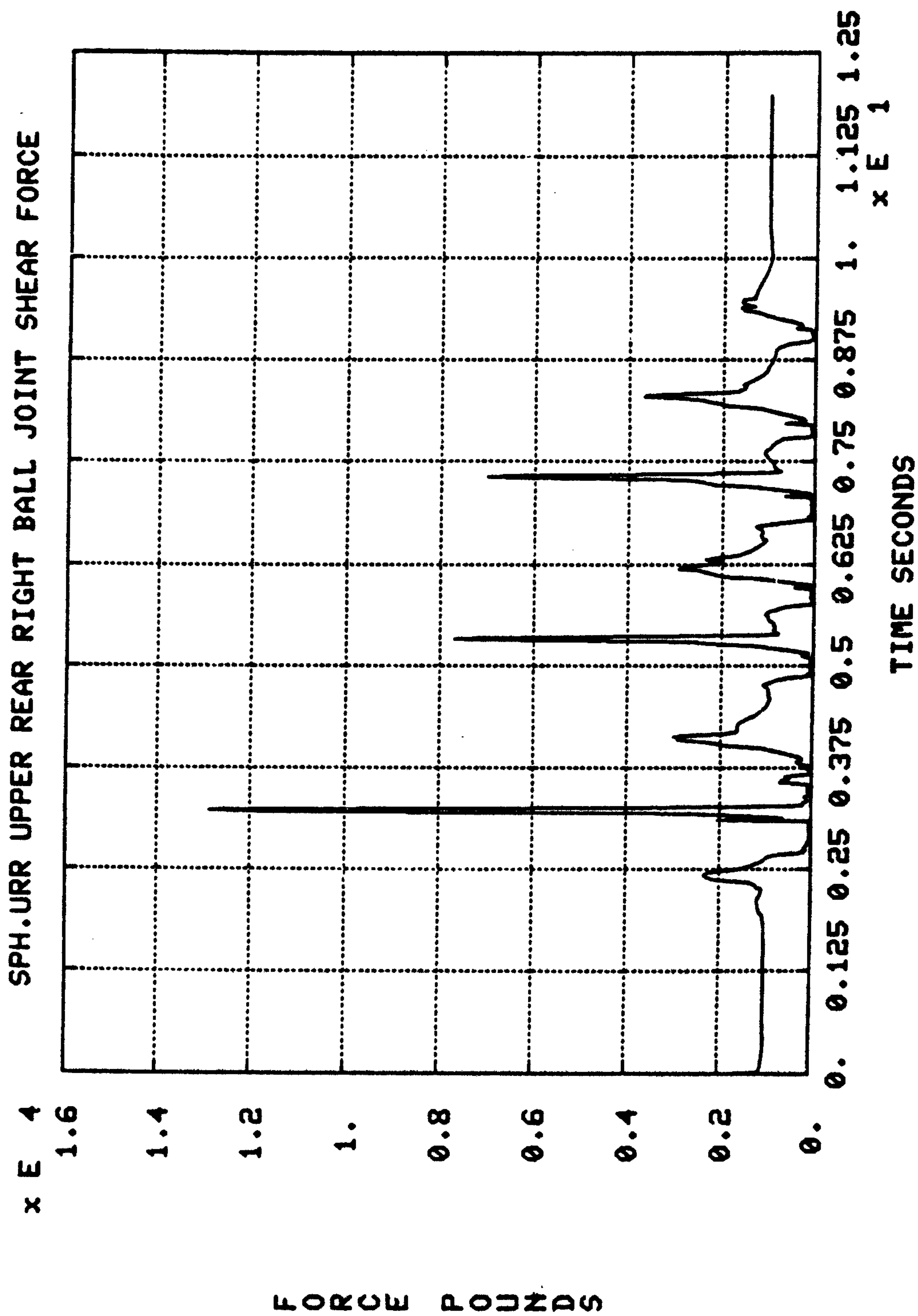


Figure 5-75. Upper Rear Right Ball Joint Shear Force

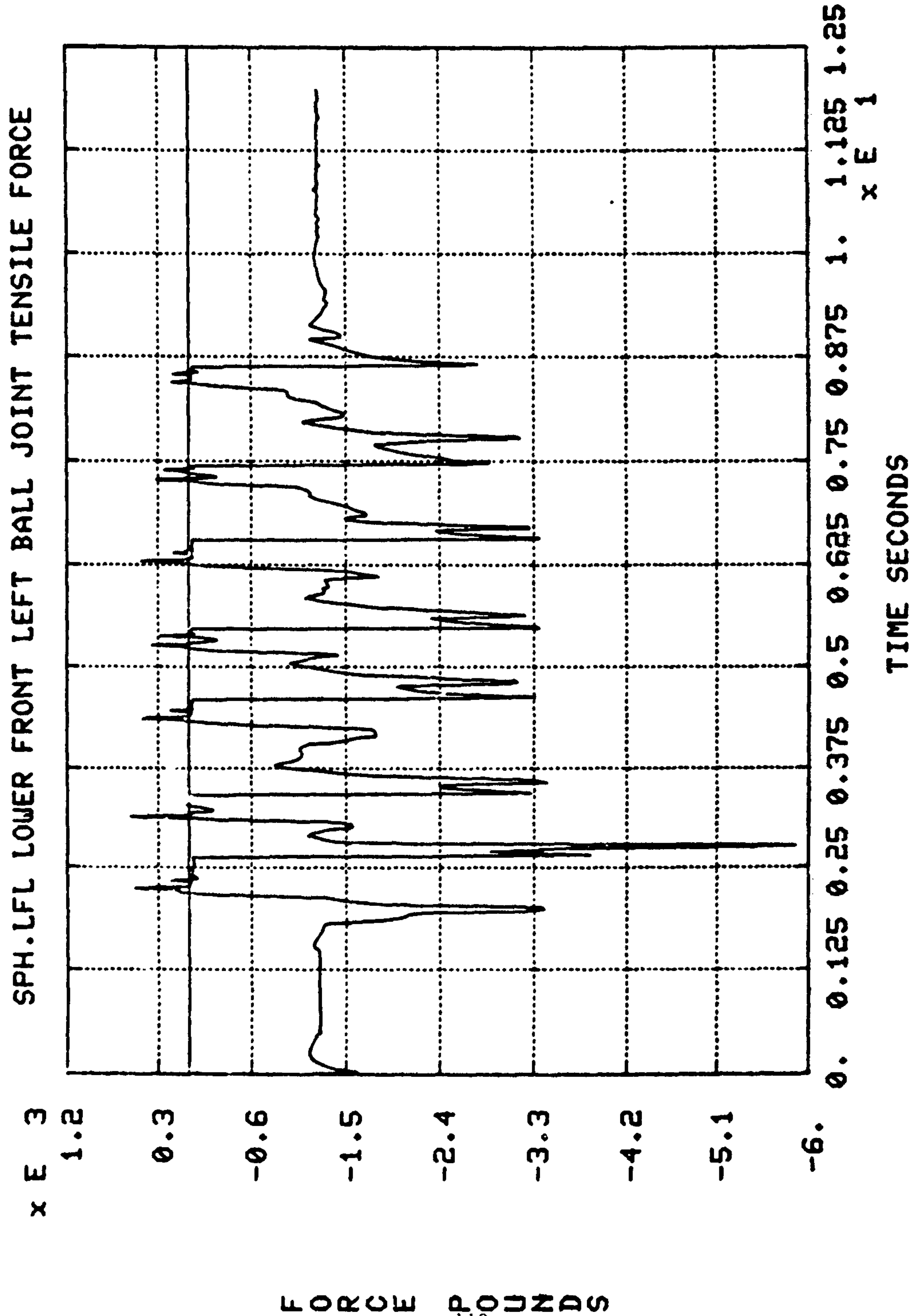


Figure 5-76. Lower Front Left Ball Joint Tensile Force

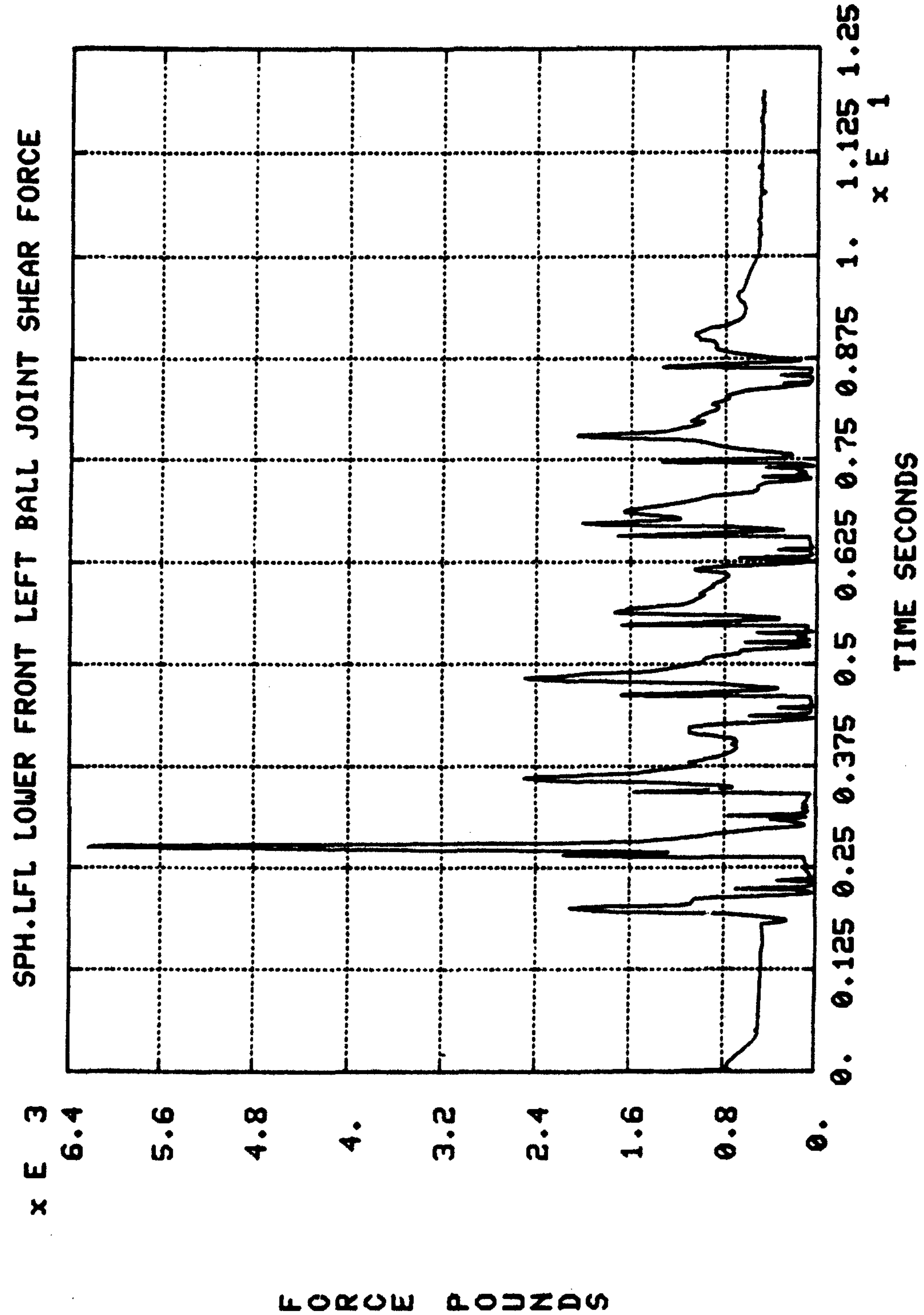


Figure 5-77. Lower Front Left Ball Joint Shear Force

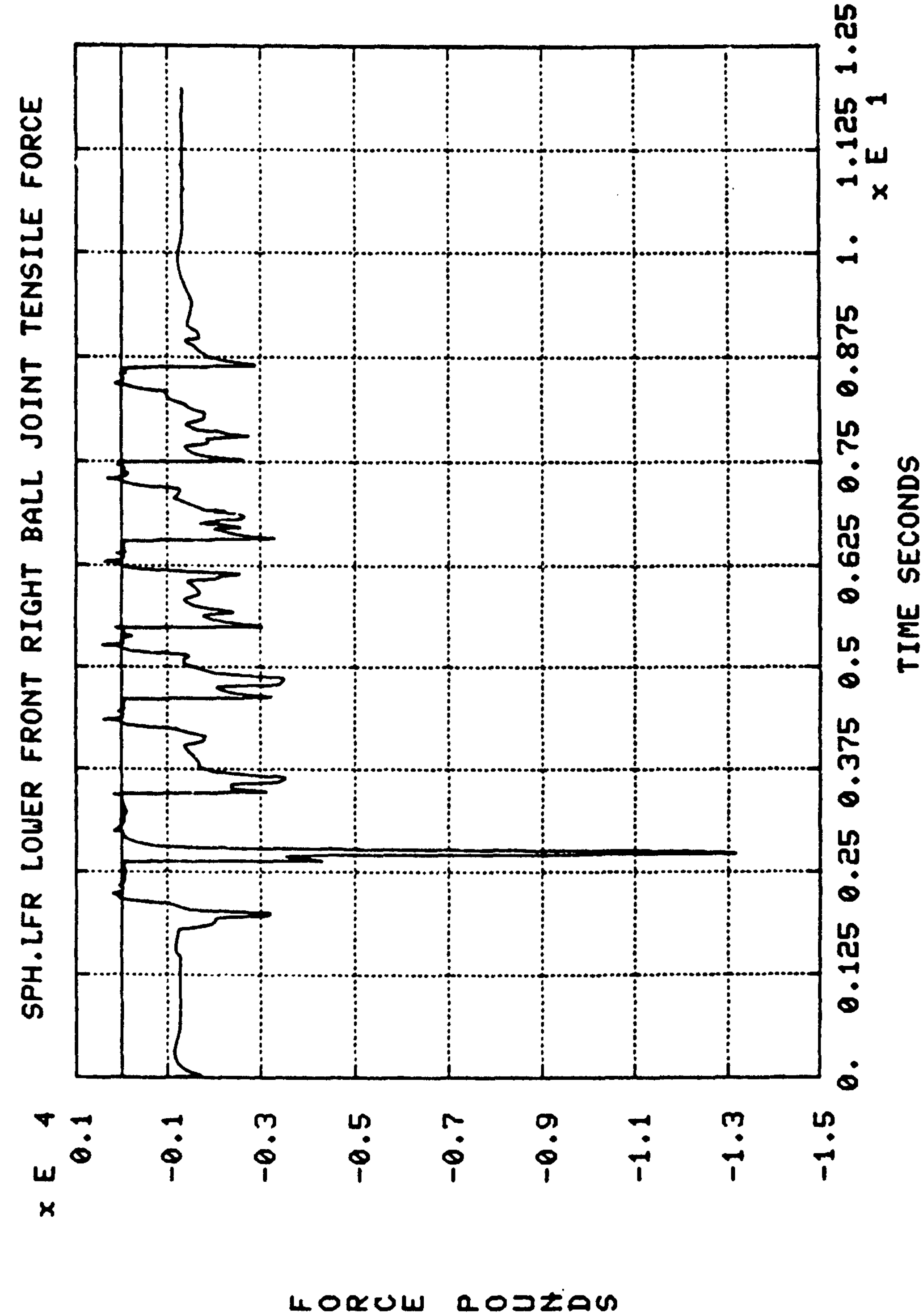


Figure 5-78. Lower Front Right Ball Joint Tensile Force

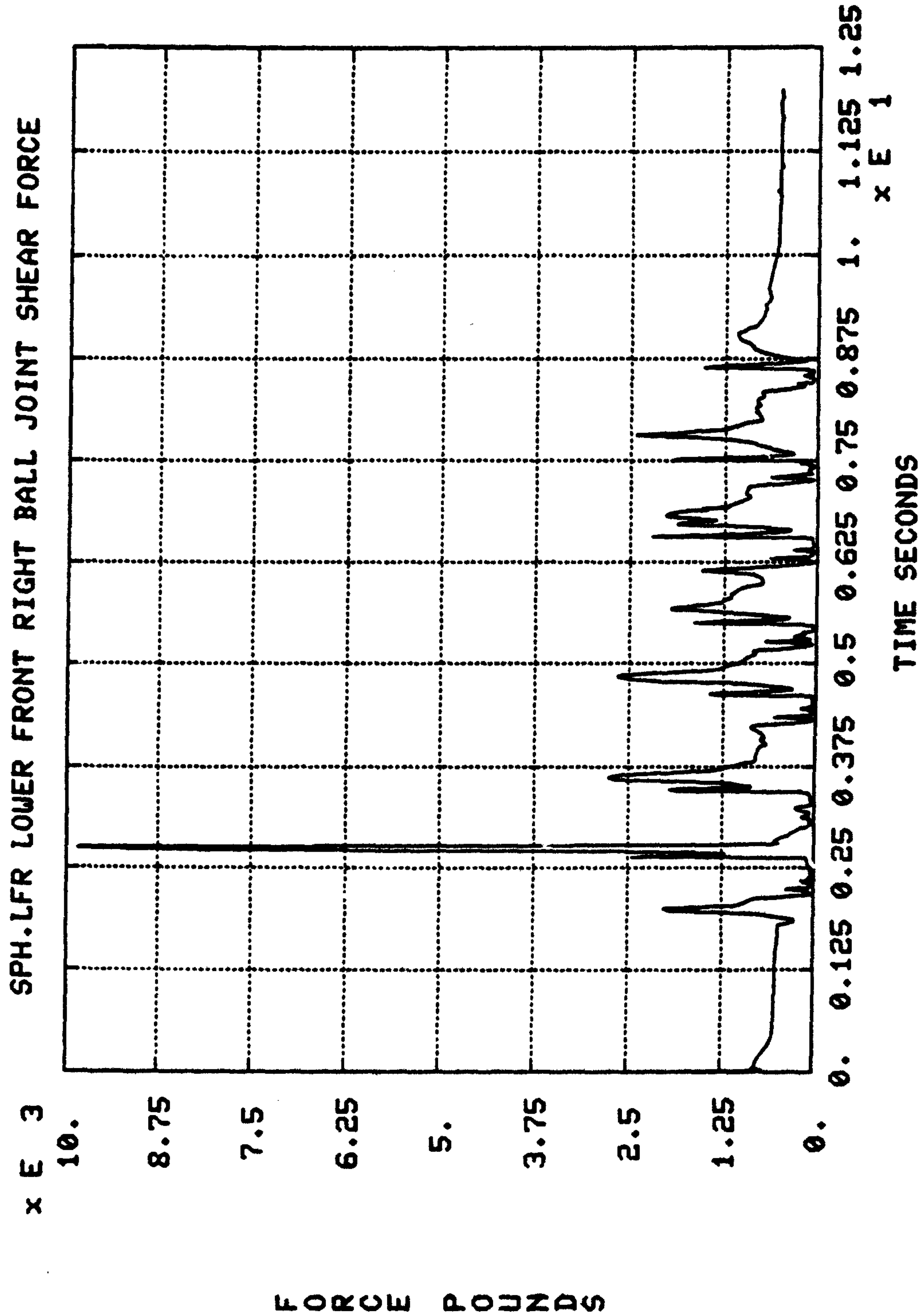


Figure 5-79. Lower Front Right Ball Joint Shear Force

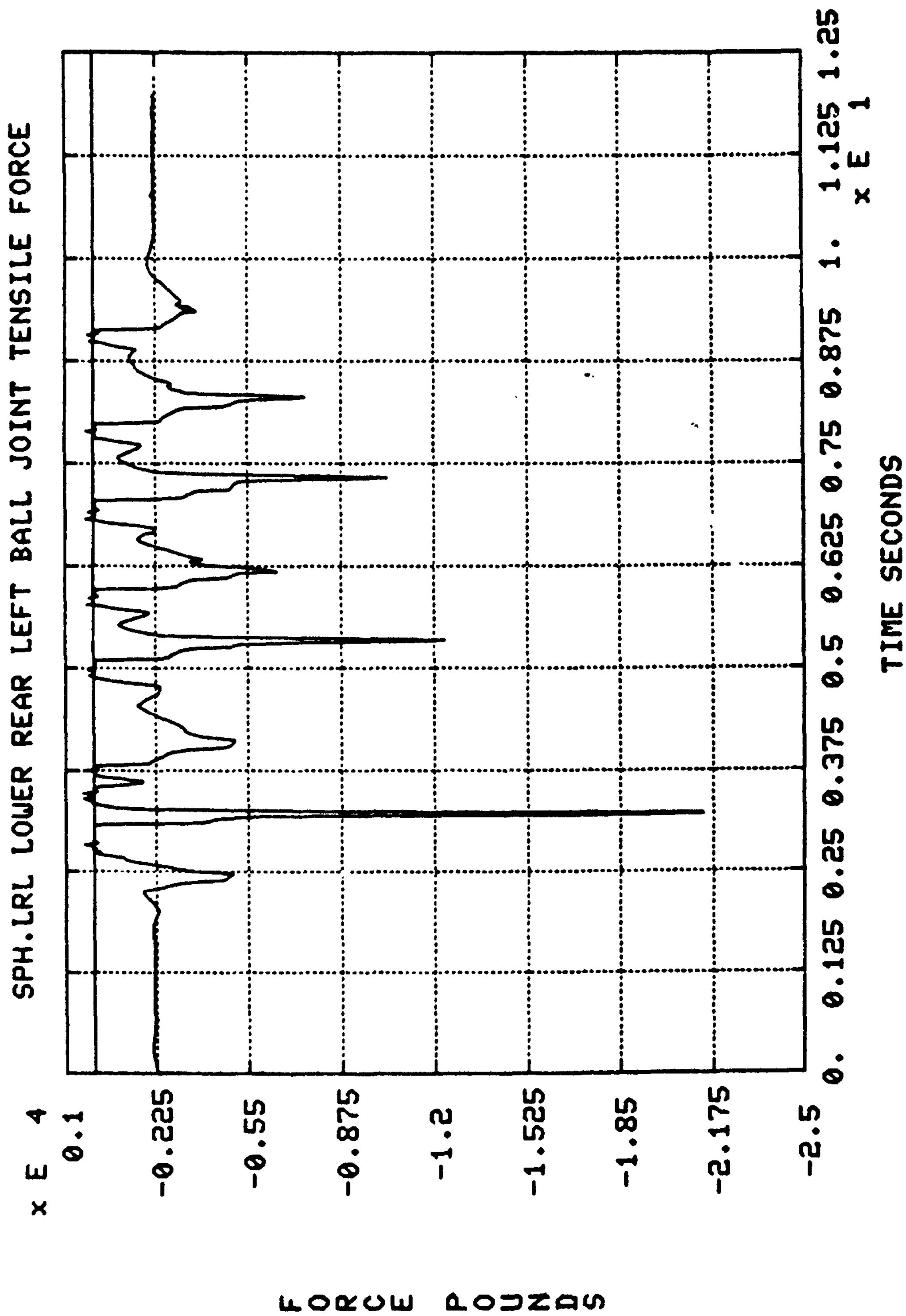


Figure 5-30. Lower Rear Left Ball Joint Tensile Force

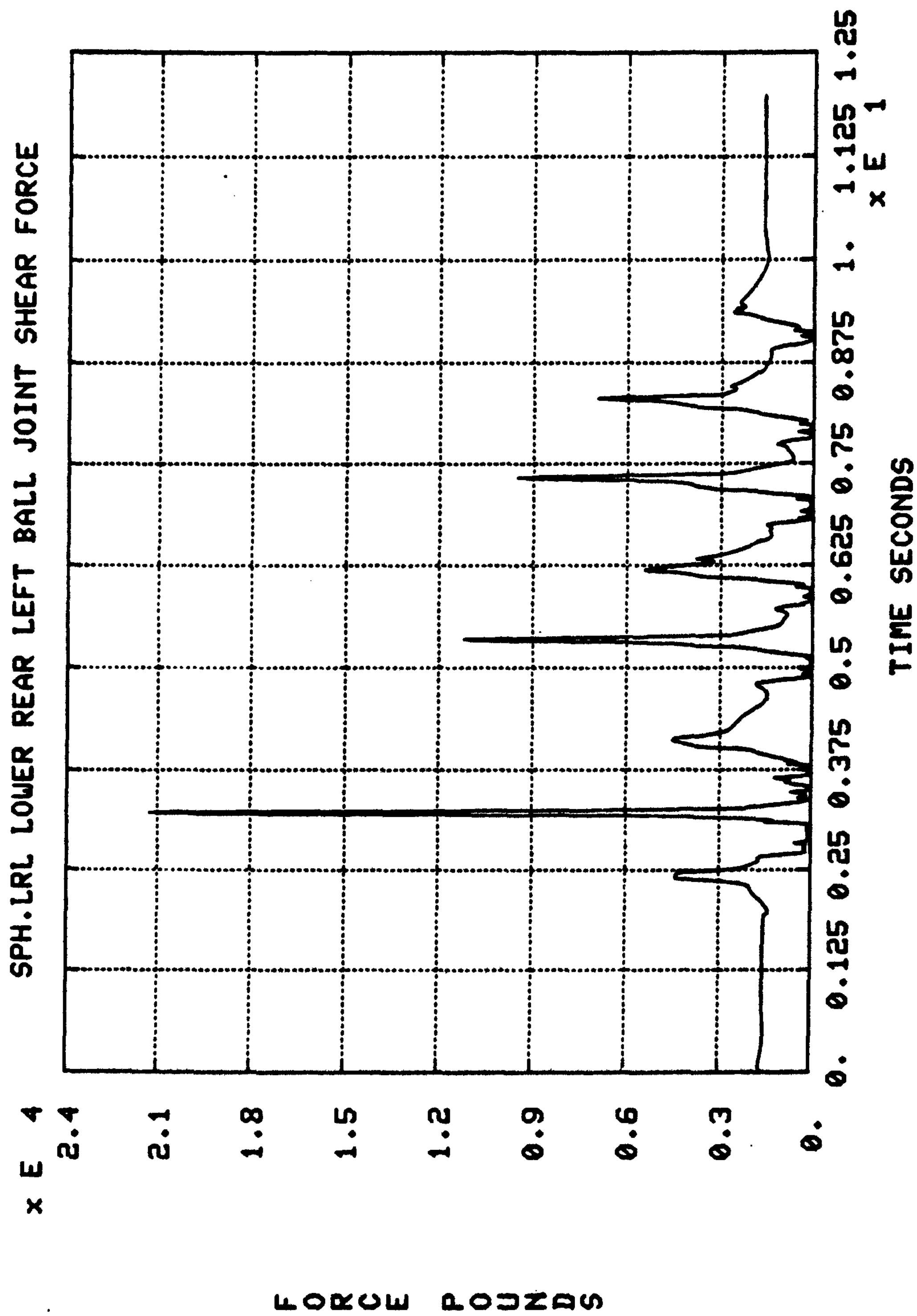


Figure 5-81. Lower Rear Left Ball Joint Shear Force

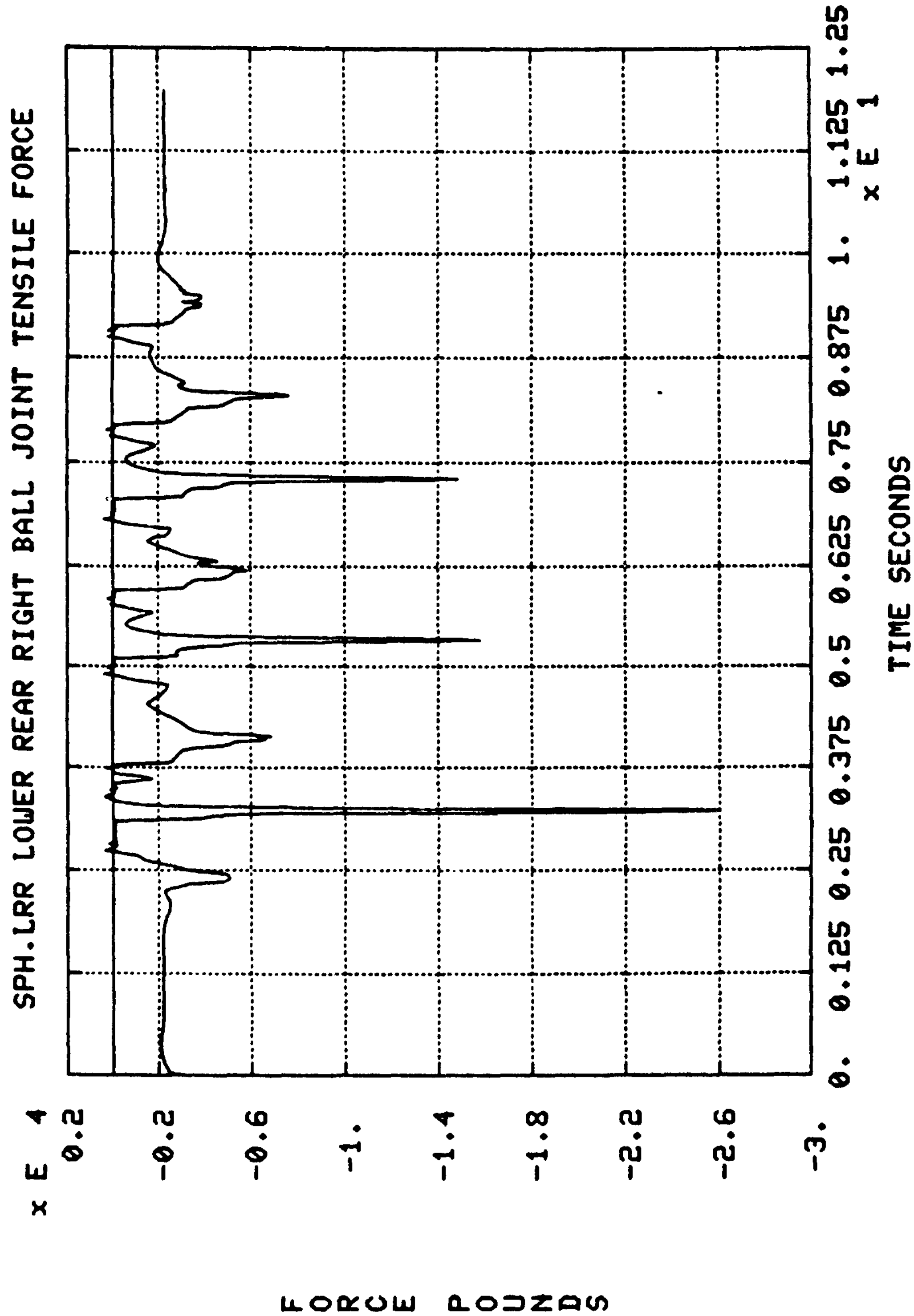


Figure 5-82. Lower Rear Right Ball Joint Tensile Force

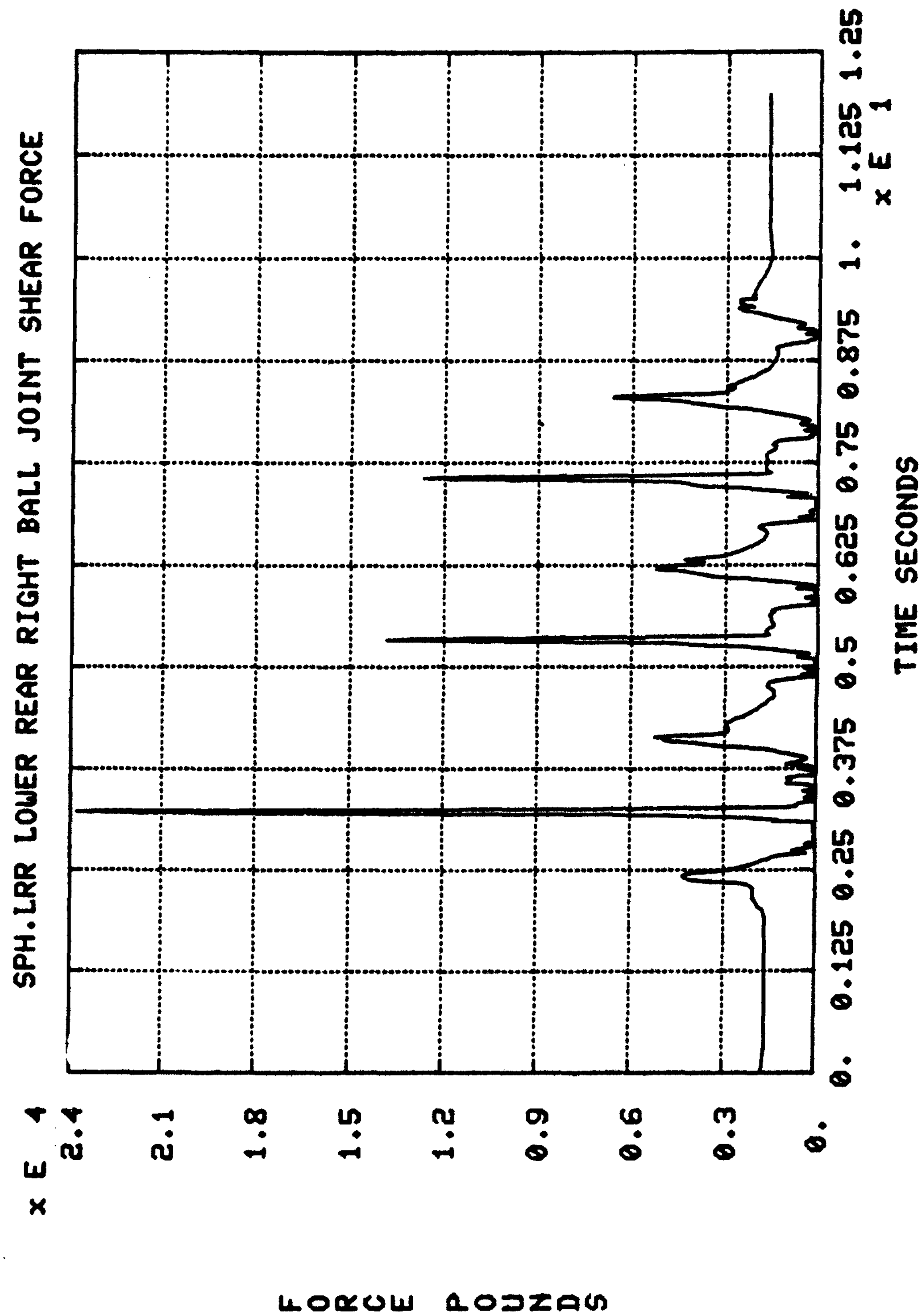


Figure 5-83. Lower Rear Right Ball Joint Shear Force

Figures 5-84 through 5-91 show the joint angle as defined in section 5.3.12. titled "Ball Joints" for each upper and lower ball joint. The calculations show that the ball joints do not exceed the recommended maximum allowable angle.

5.7. Static Analysis

5.7.1. Heavy Duty Right Rear Suspension Model. The purpose of this analysis was to determine the magnitude of the joint forces under given forces applied to the wheel body. The analysis results provide the design sensitivity of this suspension unit to externally applied forces.

The external forces applied to the wheel body included a combination of vertical, lateral, and longitudinal forces acting at the wheel and road interface. For this analysis tire dynamics were not considered and the tire radius was assumed to be constant at 16.355 inches. Also for this analysis the chassis body was fixed to ground to prevent any chassis motion.

This analysis was actually executed in dynamics mode because the shock absorber was modeled. If the combination of externally applied forces caused the shock to be compressed into the metal-to-metal region, then the shock acted as a very stiff element as explained in section 5.3.7. titled "Shock Absorber." The analysis was run for a sufficient time until static equilibrium of all elements was obtained.

The static analysis of the HMMWV heavy duty right rear suspension unit uses the same program described in section 5.6. titled "Dynamic Analysis". However, for this analysis the set of bodies, joints, and other constraint elements are limited only to the right rear suspension unit. The DADS elements listed in Table 5-19 were used to describe the HMMWV heavy duty right rear suspension unit. A sample of one *.VB3 verbatim file is given in Appendix F.

The coordinate reference frames used in this analysis are the same as those in the dynamic analysis.

Six combinations of externally applied vertical, lateral, and longitudinal forces were analyzed. For each combination the vertical force was increased by 2,500-pound increments. Based upon a coefficient of friction equal to 0.5 between the wheel and road, which is equivalent to a gravel road, the lateral and longitudinal forces were assumed to be one-half the magnitude of the vertical forces. No applied torques are generated by the vertical force because the line of action is through the wheel center. No applied torques generated by the fore-aft longitudinal forces were placed upon the wheel body because these torques are transmitted directly through the half drive shaft assembly. The six loading combinations which were analyzed and their directory location on the VAX8800 computer are given in Table 5-20.

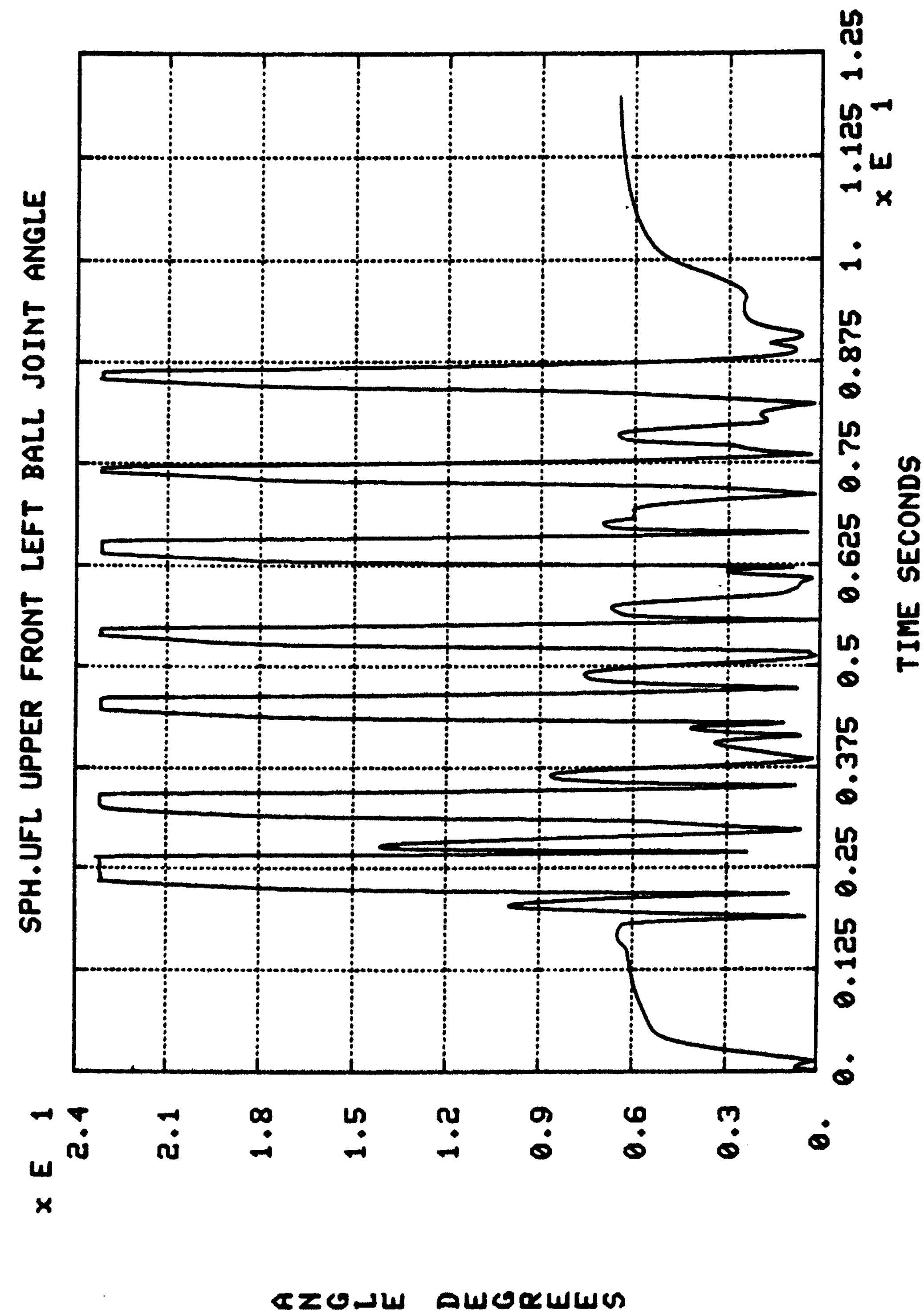


Figure 5-84. Upper Front Left Ball Joint Angle

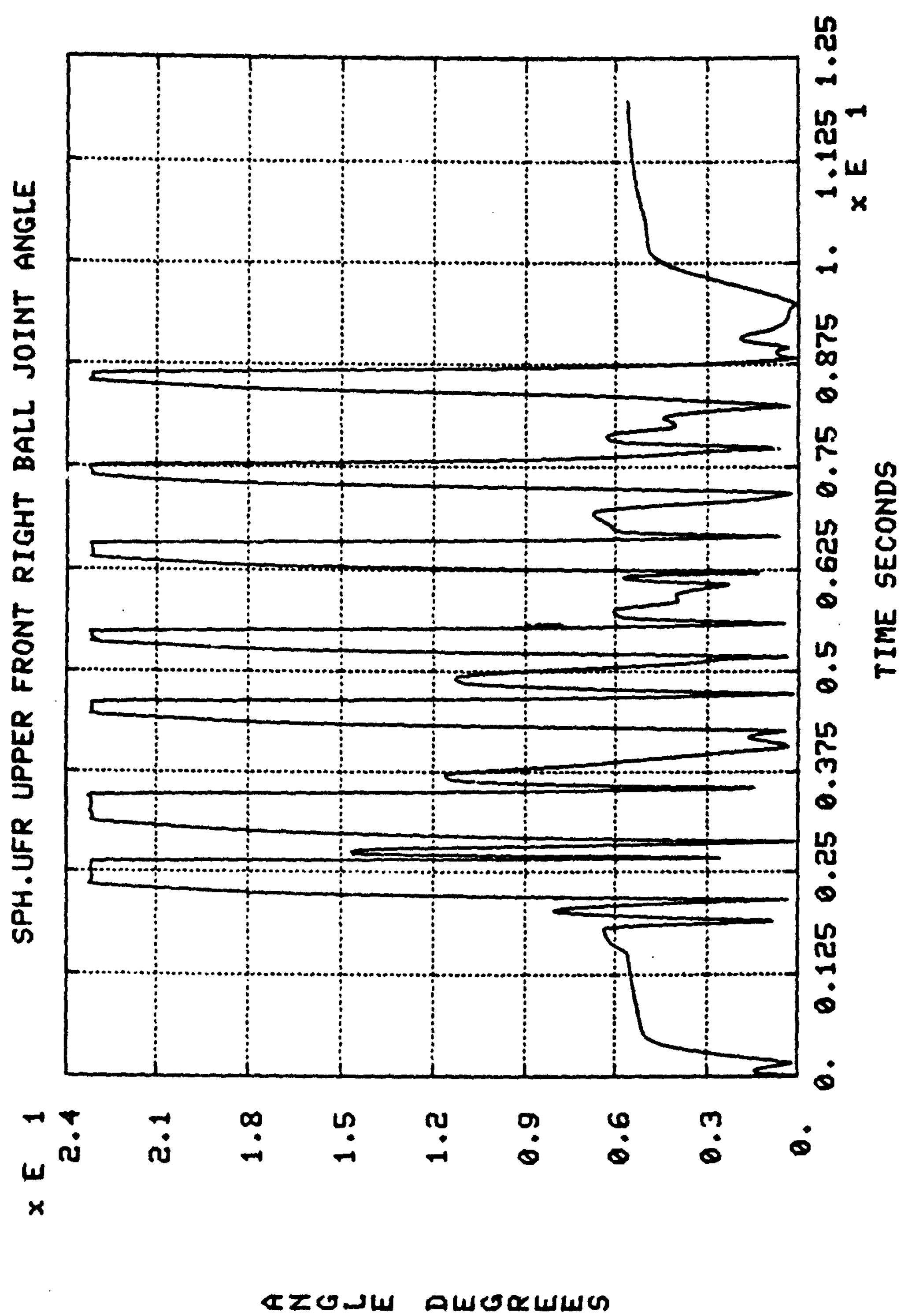


Figure 5-85. Upper Front Right Ball Joint Angle

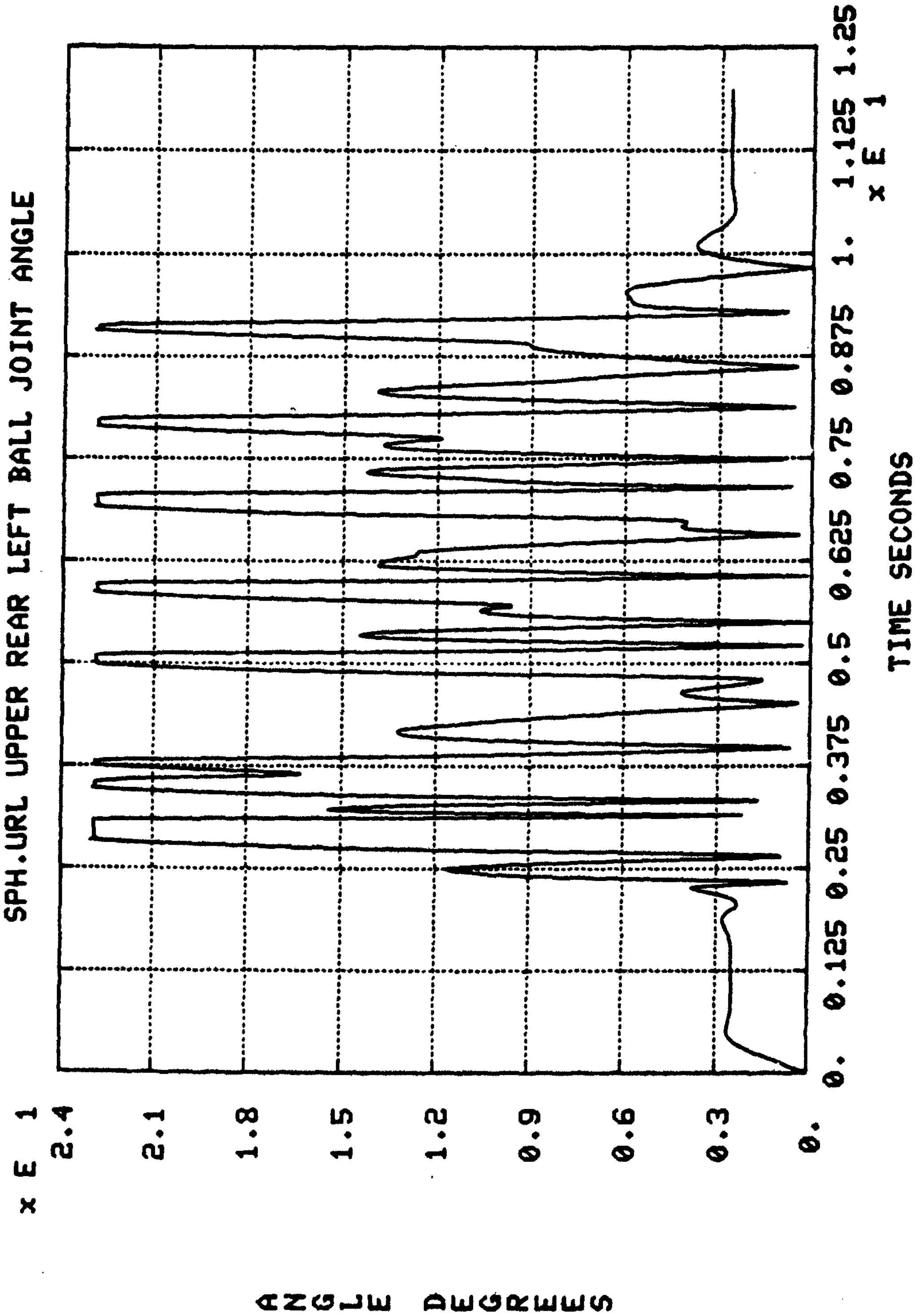


Figure 5-86. Upper Rear Left Ball Joint Angle

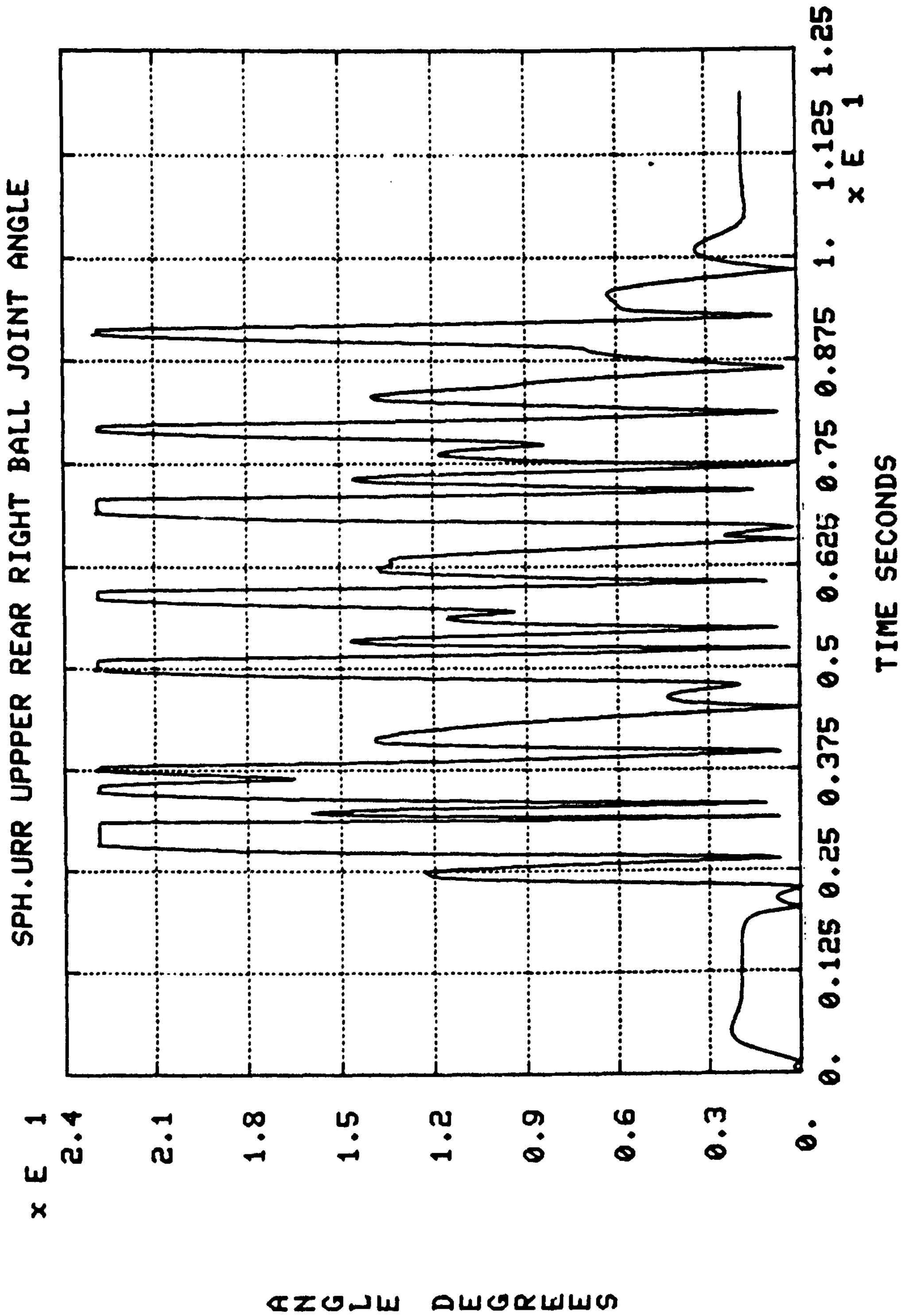


Figure 5-87. Upper Rear Right Ball Joint Angle

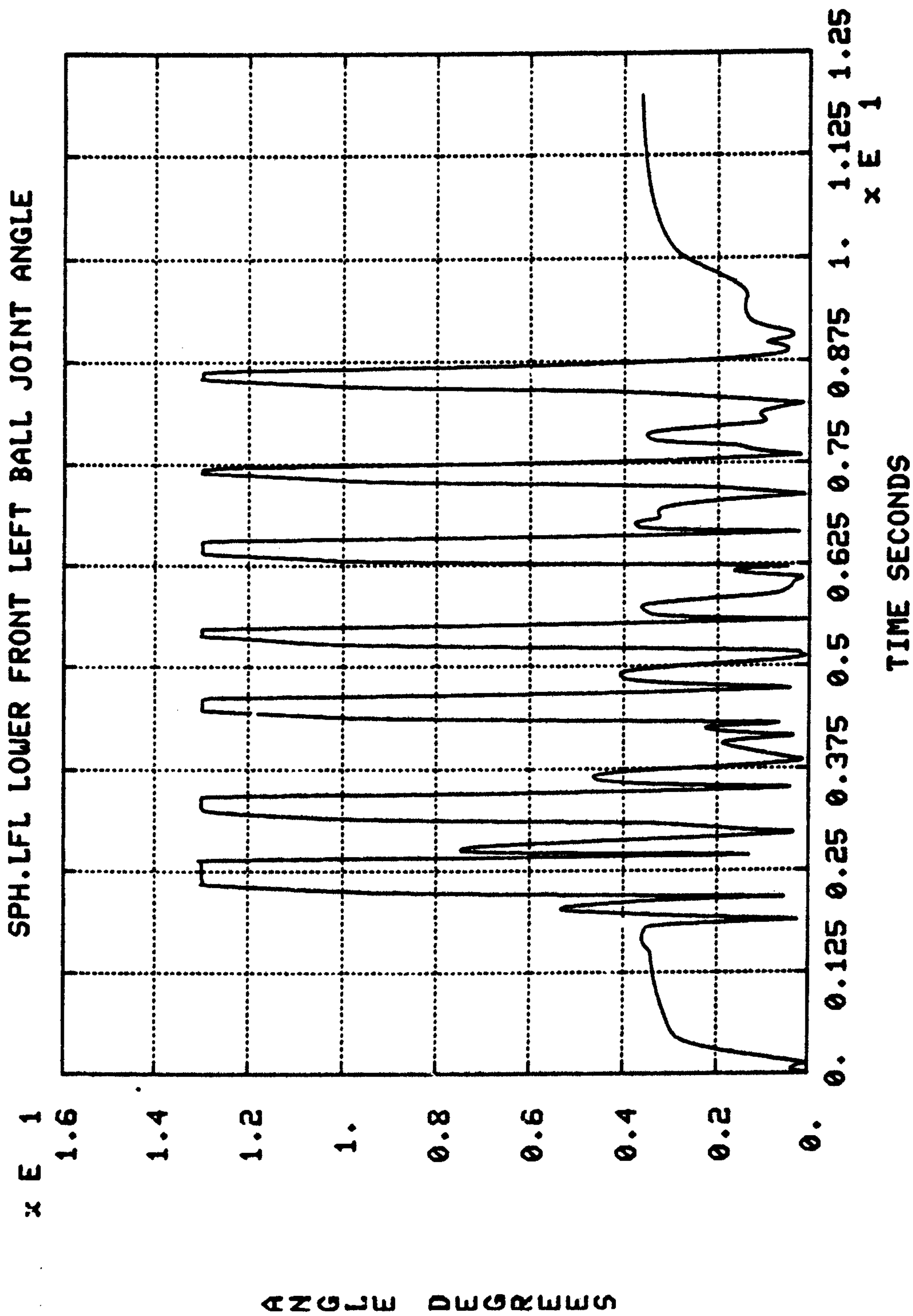


Figure 5-88. Lower Front Left Ball Joint Angle

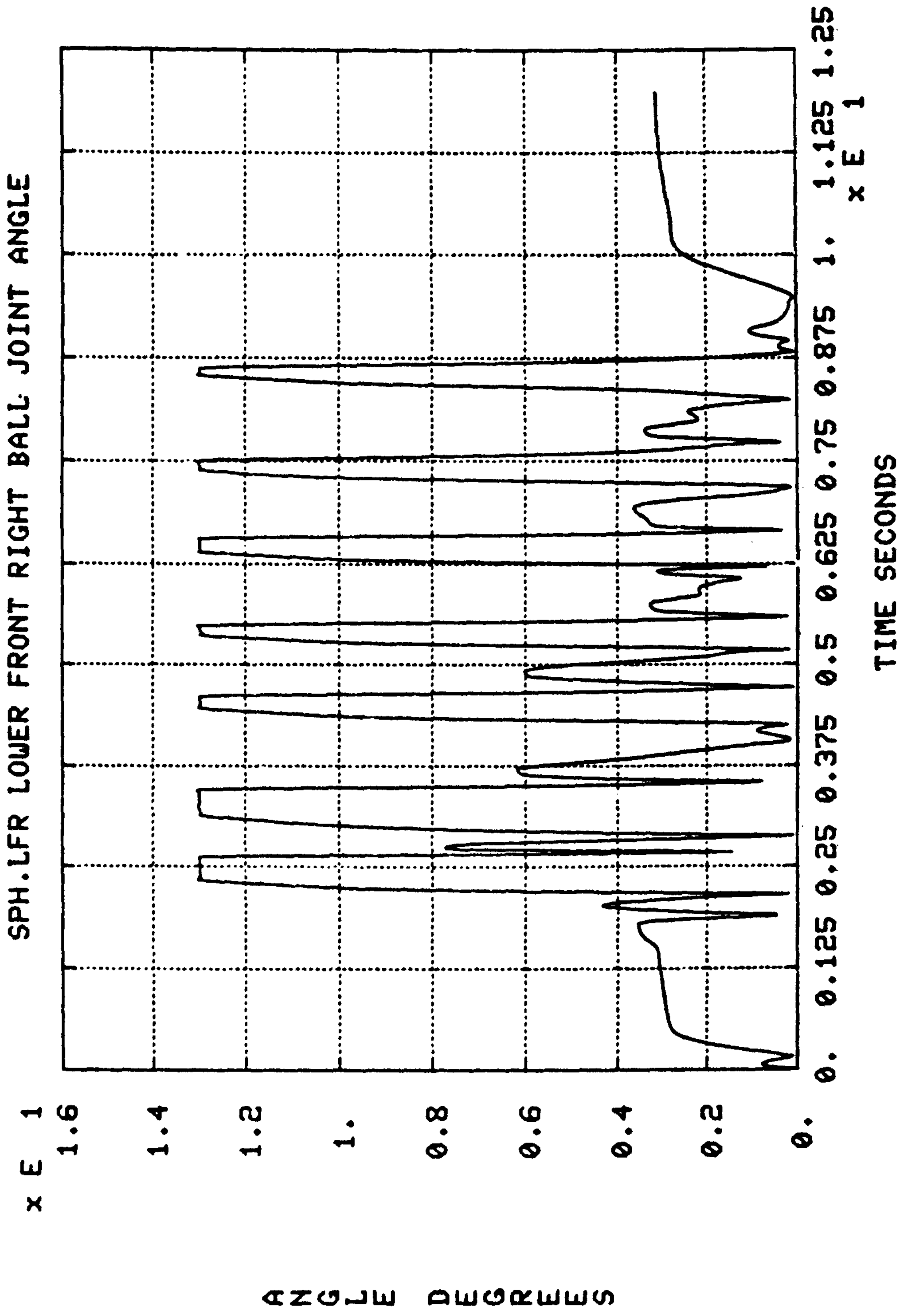


Figure 5.80 Lower Front Right Ball Joint Angle

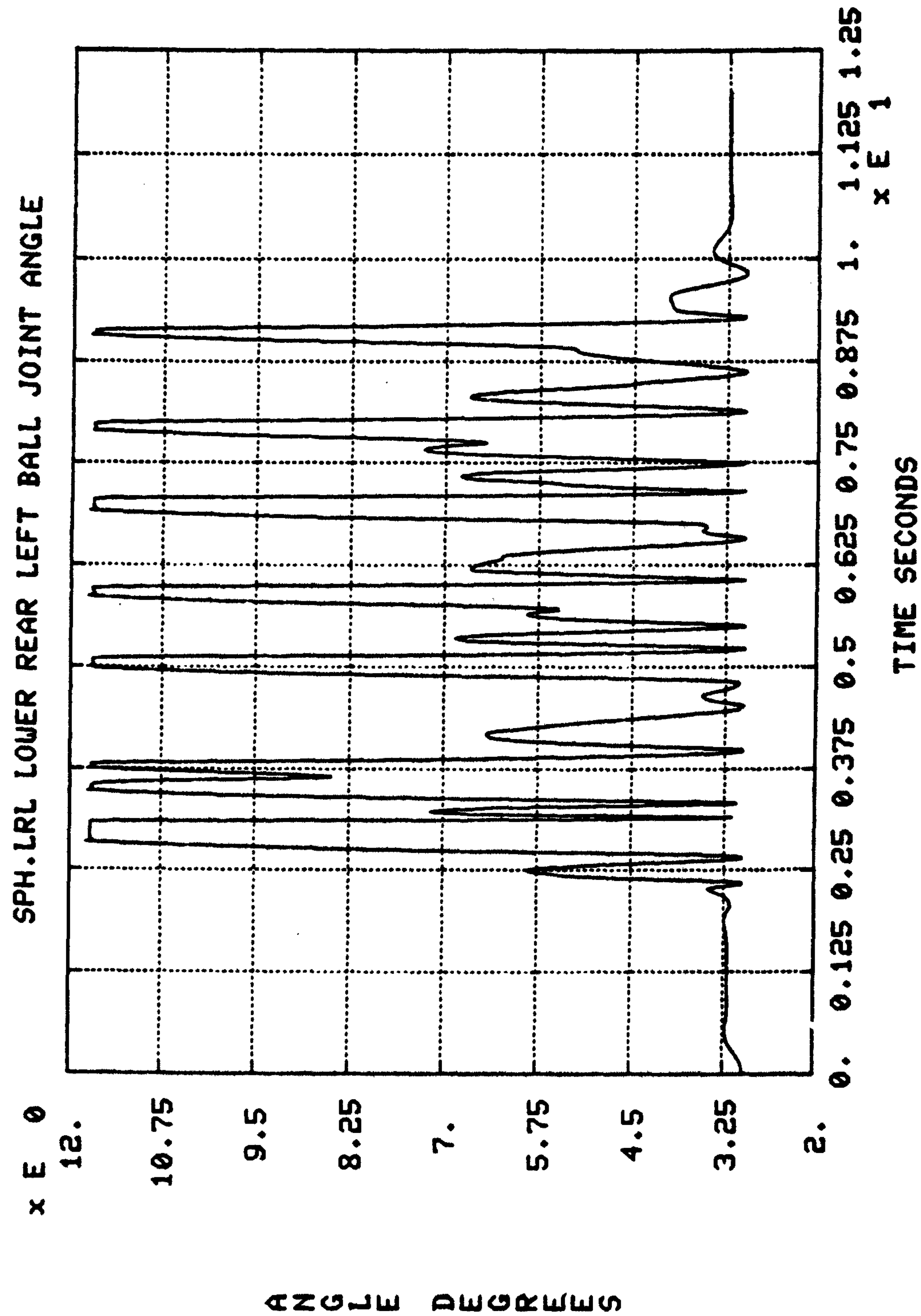


Figure 5-90. Lower Rear Left Ball Joint Angle

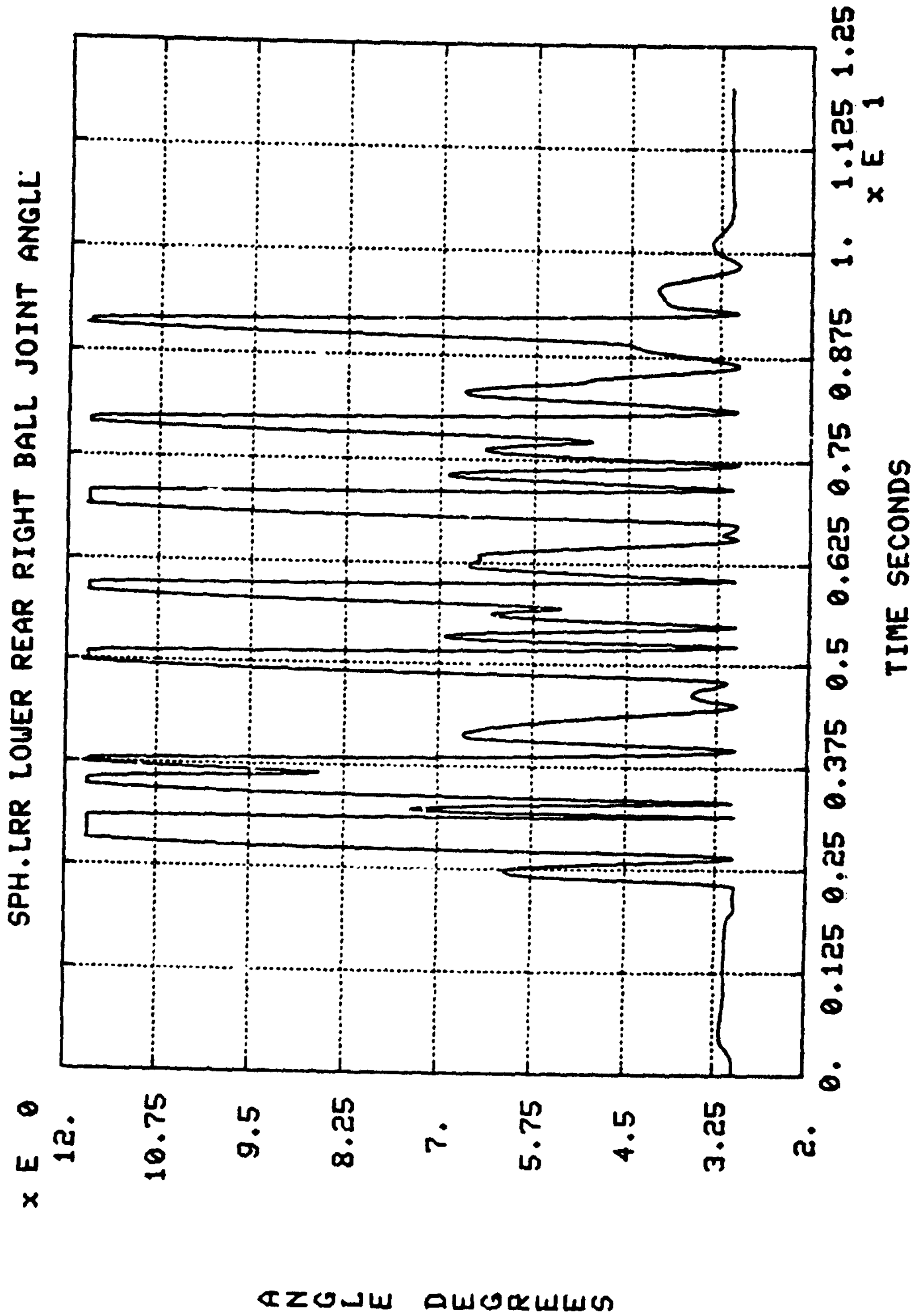


Figure 5-91. Lower Rear Right Ball Joint Angle

Table 5-19. DADS Elements

DADS ELEMENT	ELEMENT NAME	DESCRIPTION
HEADER	HEADER	Comments
SYSTEM	SYSTEM.DATA	Simulation Parameters
DYNAMIC	DYNAMIC.DATA	Simulation Parameters
DISTANCE.CONSTRAINT	RAD-ROD.RR	Rear Right Rad Rod
TSDA	DUMMY_TSDA_1	Increment Counter
TSDA	DUMMY_TSDA_2	Increment Counter
TSDA	DUMMY_TSDA_3	Increment Counter
TSDA	SPRING.RR	Rear Right Spring
TSDA	SHOCK.RR	Rear Right Shock
REVOLUTE.JOINT	REV.LRR	Lower Rear Right
REVOLUTE.JOINT	REV.URR	Upper Rear Rear Right
SPHERICAL	SPH.LRR	Lower Rear Right
SPHERICAL	SPH.URR	Upper Rear Right
BODY	CHASSIS	Fixed to Ground
BODY	ARM.LRR	Lower Rear Right
BODY	ARM.URR	Upper Rear Right
BODY	WHEEL.RR	Rear Right Wheel
INITIAL.CONDITION	INIT.WHEEL.RR	Rear Right Wheel Z

Table 5-20. Static Loading Combinations and Directory Locations

Loading	Directory
Vertical Forces	[AARDEMA.DADS3D.HMMWV.1037.REAR_SUSP.FORCE_Z]
Vertical and Forward Longitudinal Forces	[AARDEMA.DADS3D.HMMWV.1037.REAR_SUSP.FORCE_Y.POS_Y]
Vertical and Rearward Longitudinal Forces	[AARDEMA.DADS3D.HMMWV.1037.REAR_SUSP.FORCE_Y.NEG_Y]
Vertical and Outward Lateral Forces	[AARDEMA.DADS3D.HMMWV.1037.REAR_SUSP.FORCE_X.POS_X]
Vertical and Inward Lateral Forces	[AARDEMA.DADS3D.HMMWV.1037.REAR_SUSP.FORCE_X.NEG_X]
Vertical and Forward Longitudinal Outward Lateral Forces	[AARDEMA.DADS3D.HMMWV.1037.REAR_SUSP.FORCE_XYZ]

Forward longitudinal forces are generated during acceleration and rearward longitudinal forces are generated during braking. For the right rear suspension unit, outward lateral forces are generated during a right turn and inward lateral forces are generated during left turns. Vertical forces are generated to support the vehicle.

5.7.2. Results. Results for the six combinations of loading are plotted in Figures 5-92 through 5-97. Tensile forces act along the kingpin axis. The kingpin axis is the line between the two ball joints. Shear force is the magnitude of the forces perpendicular to the kingpin axis acting at the center of the ball.

Based upon the stress theories discussed in section 5.6.4. titled "Dynamic Results," the shear forces are more dangerous than tensile forces. Comparing Figures 5-93 and 5-94, the shear forces in the lower arm ball joint are greater when the fore-aft longitudinal forces are in the forward direction. Likewise, comparing Figures 5-95 and 5-96, shear forces in the lower ball joint are greater for outward lateral forces than for inward lateral forces. Thus, the worst case occurs when the combination of forces include both forward longitudinal forces and outward lateral forces and this case is shown in Figure 5-97. For this condition the shear forces in the lower arm ball joint increase greatly with only relatively small increases in the externally applied forces. This analysis shows that the rear lower ball joint is most sensitive to a combination of forward longitudinal forces and outward lateral forces along with the vertical support forces applied to the wheel.

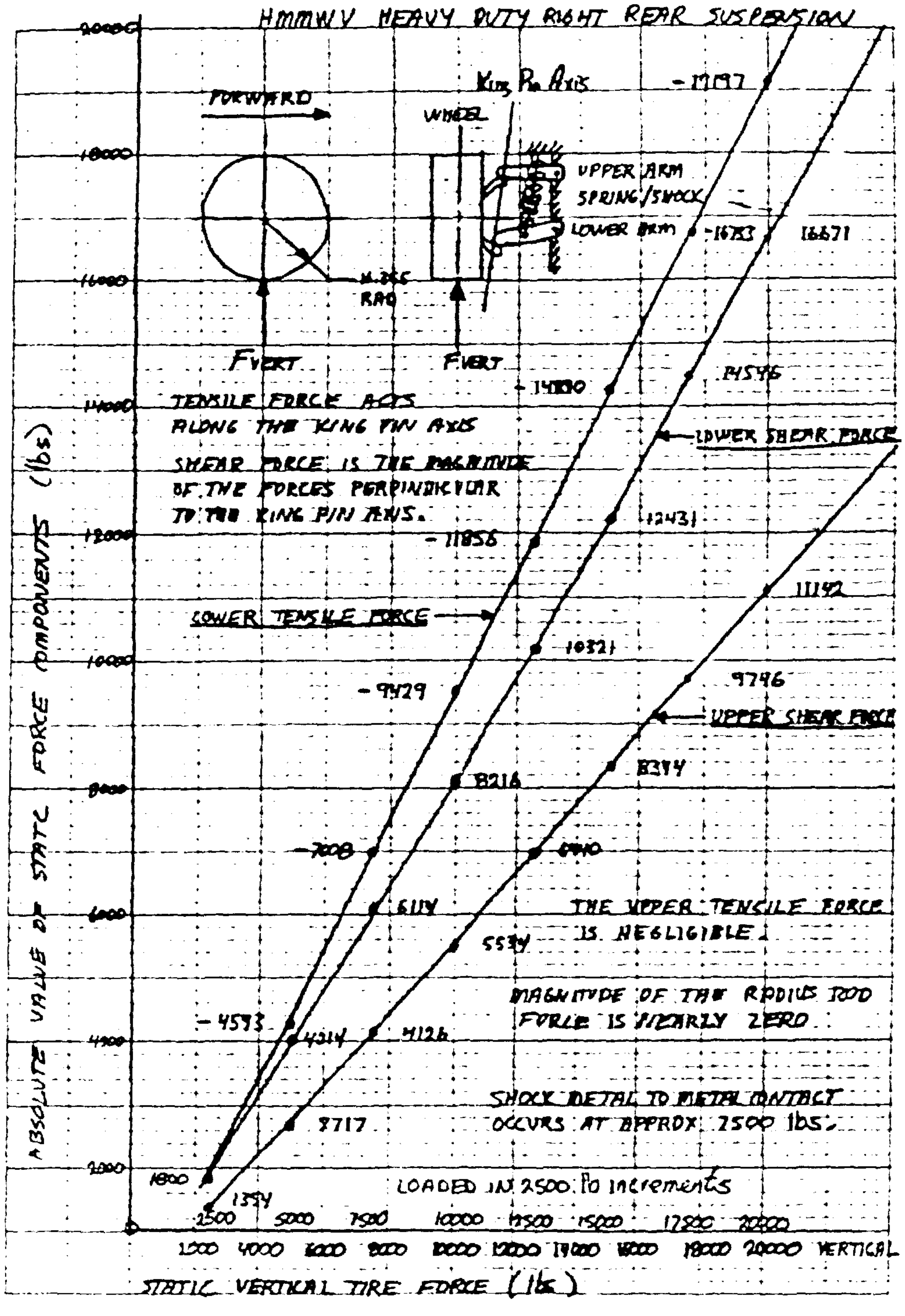


Figure 5-92. Static Vertical Tire Force

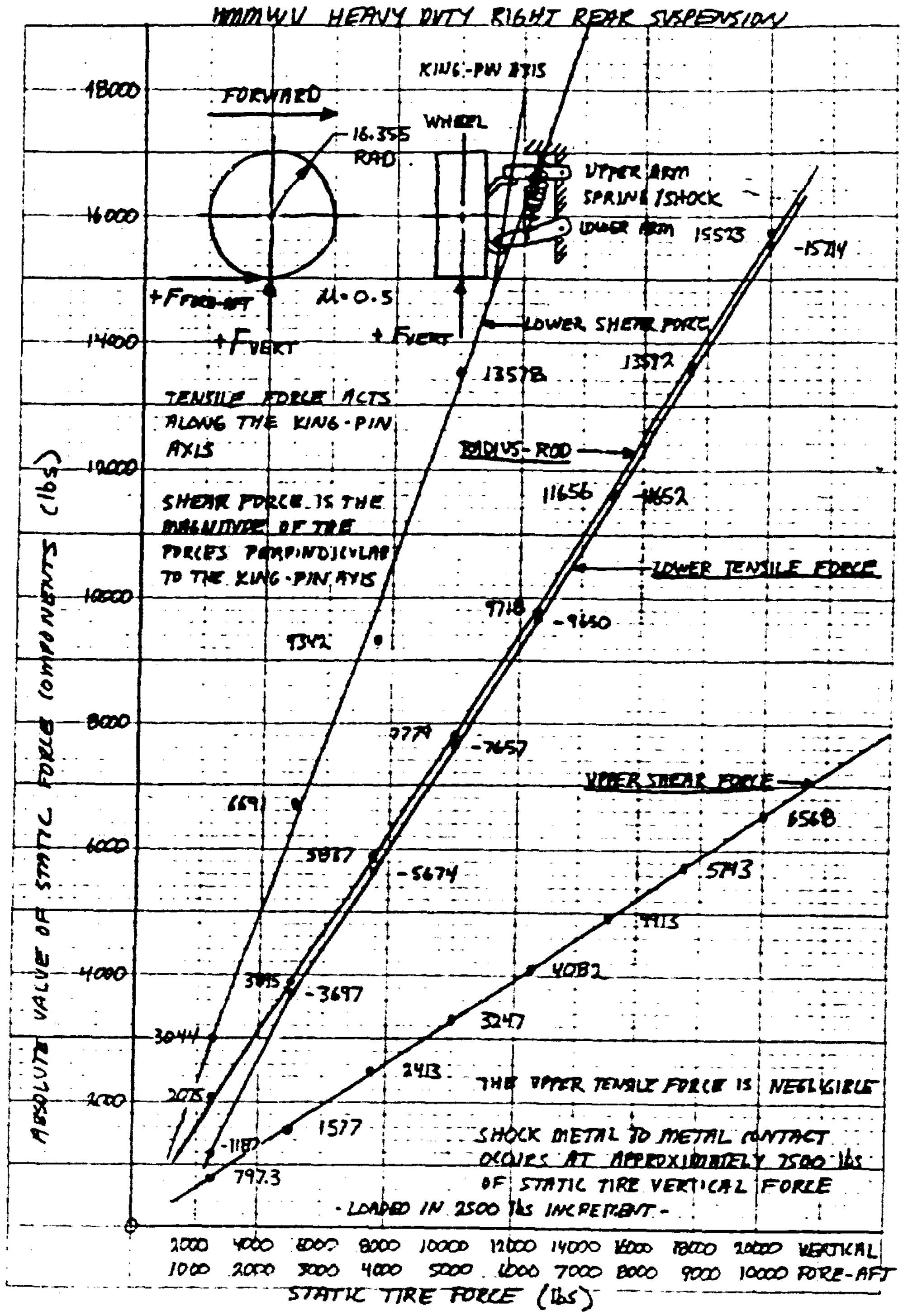


Figure 5-93. Static Vertical and Forward Longitudinal Forces

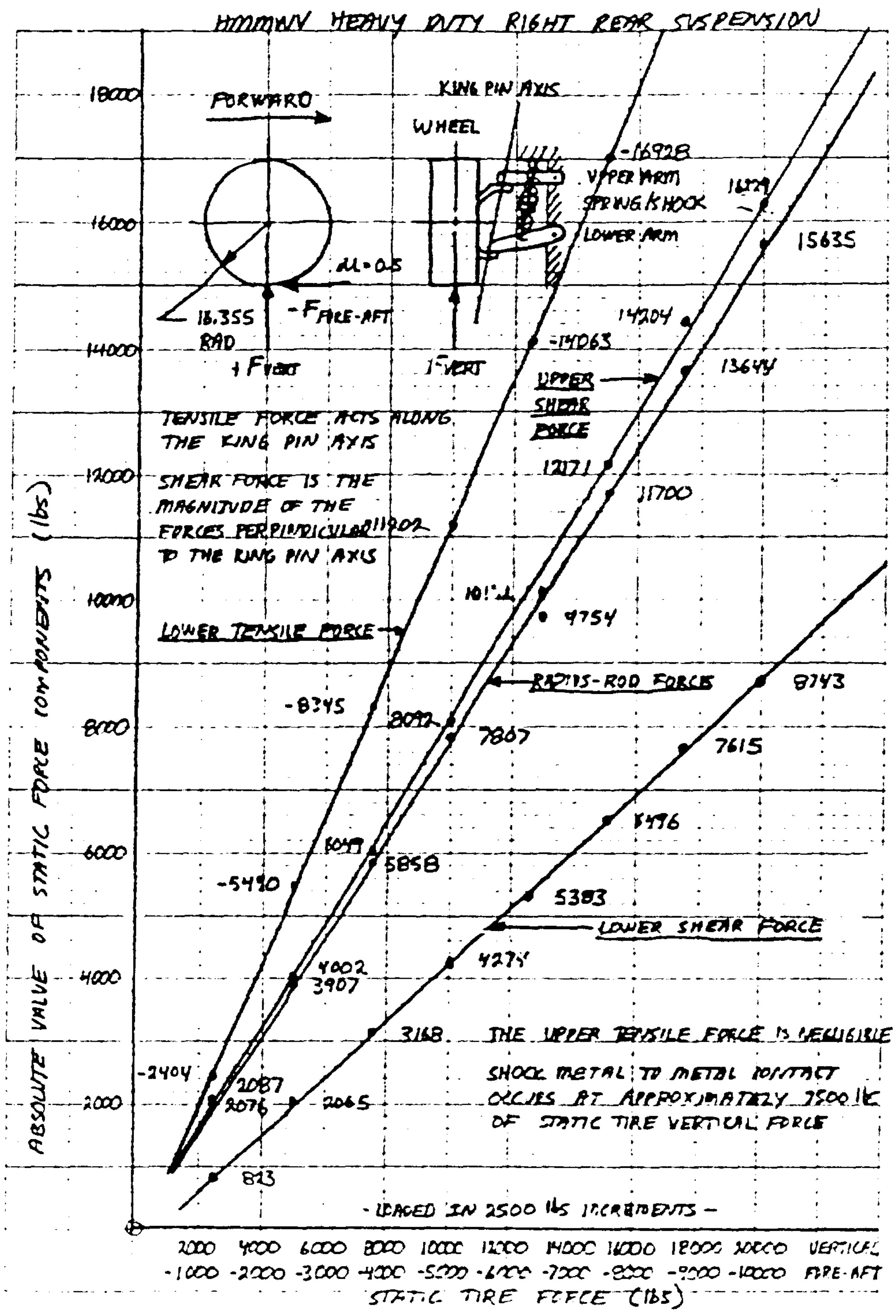


Figure 5-94. Static Vertical and Rearward Longitudinal Forces

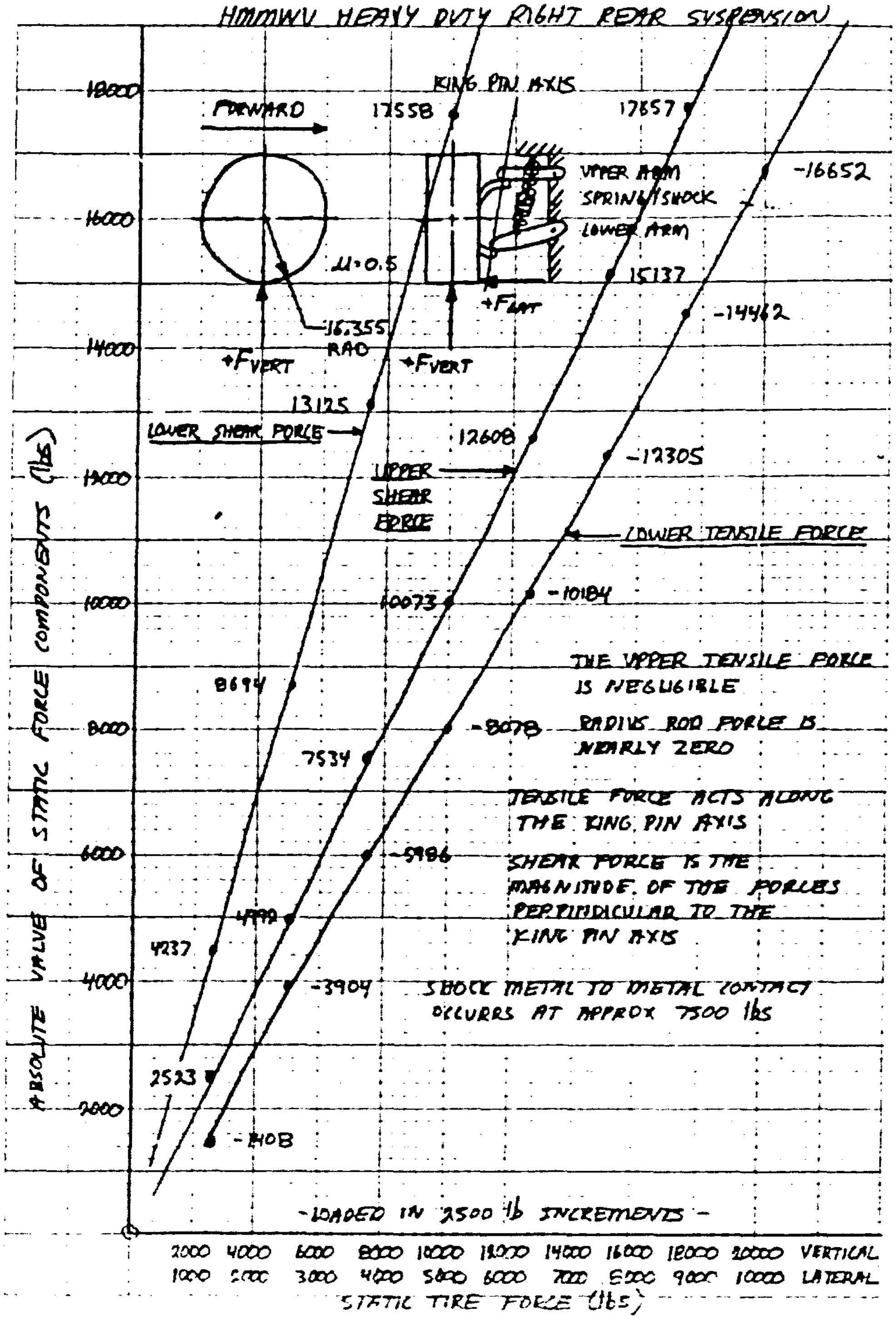


Figure 5-95. Static Vertical and Outward Lateral Forces

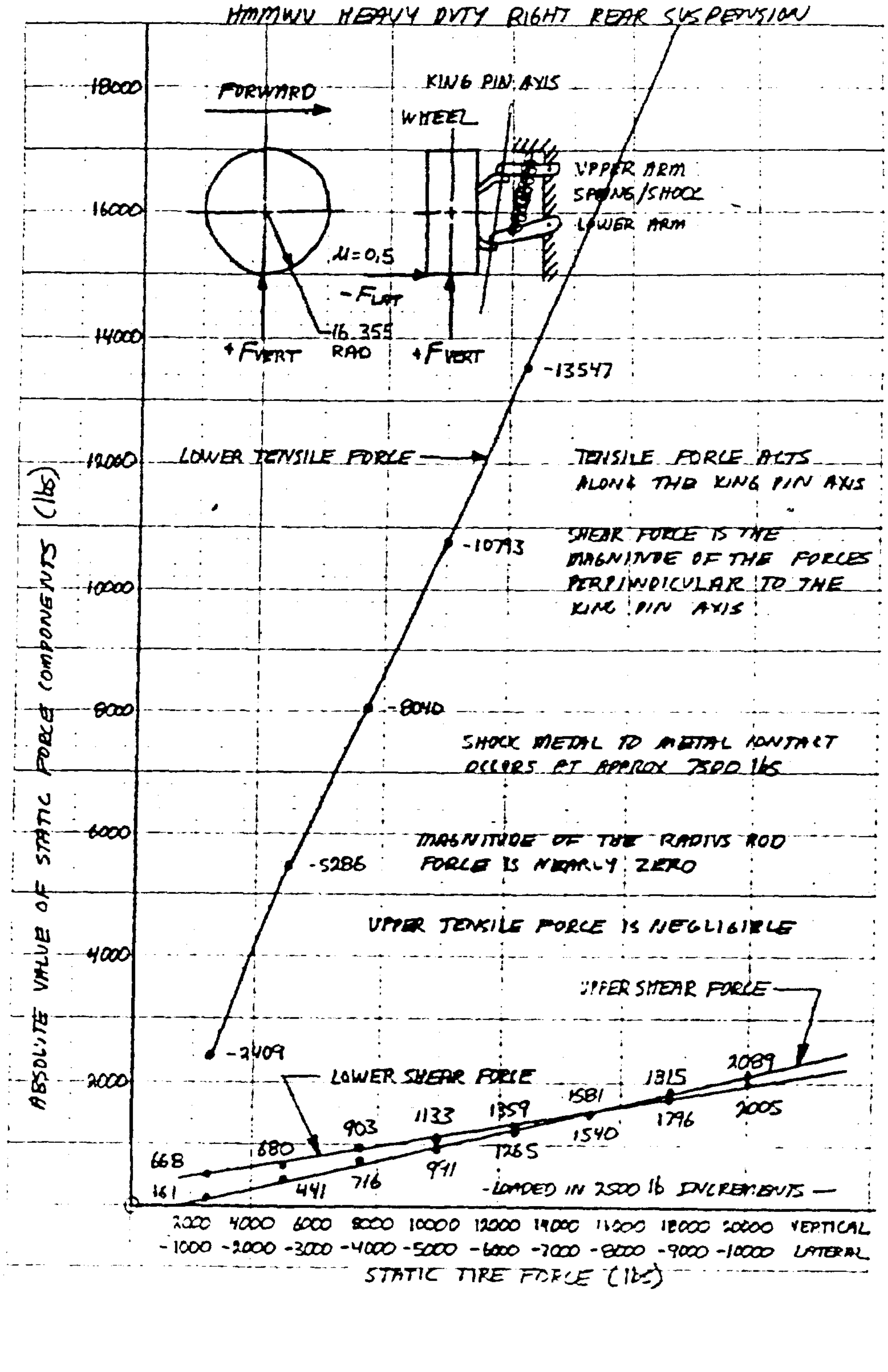


Figure 5-96. Static Vertical and Inward Lateral Forces

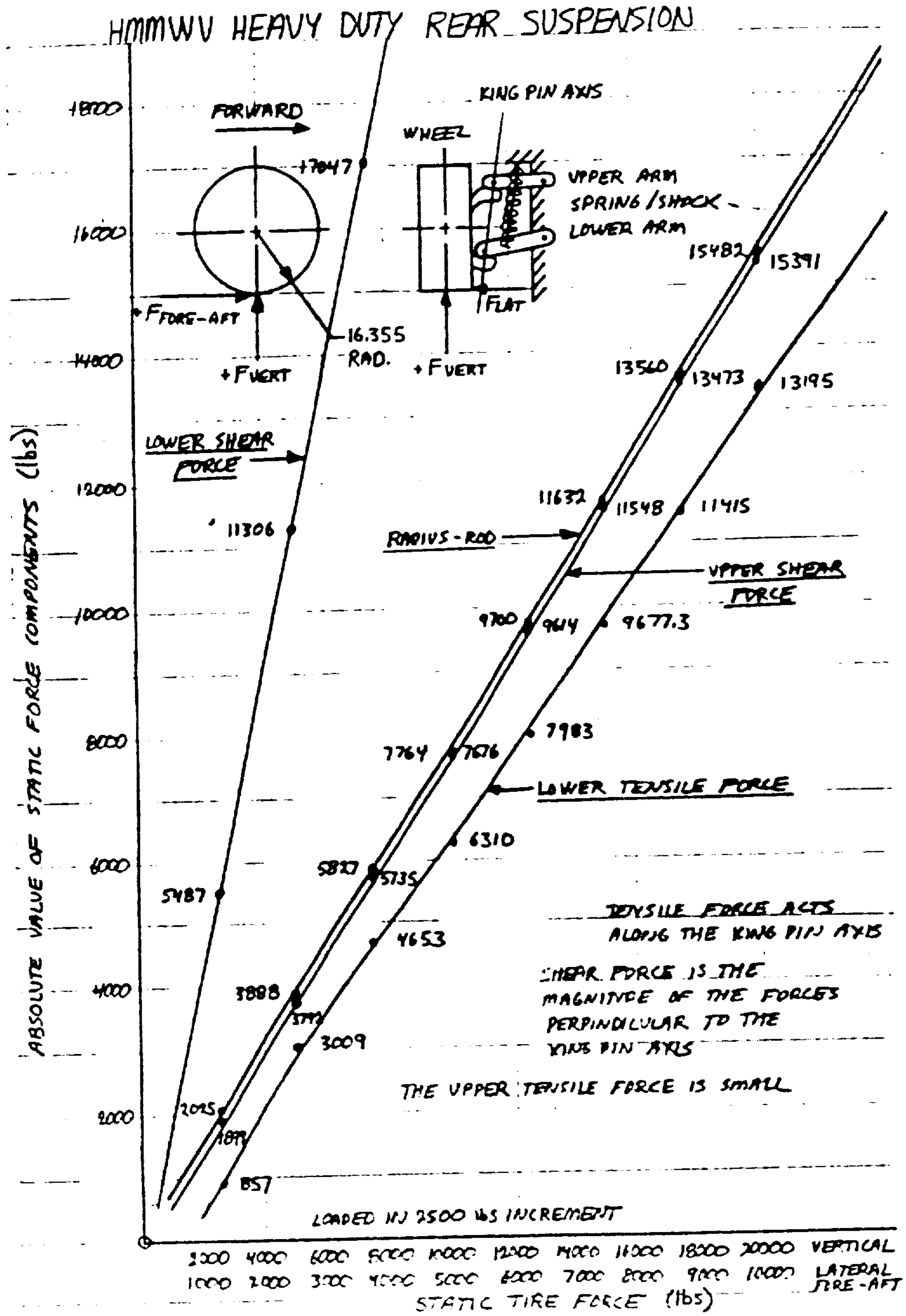


Figure 5-97. Static Vertical, Forward Longitudinal, and Outward Lateral Forces

LIST OF REFERENCES

1 SAE J670d, "Vehicle Dynamics Terminology," SAE Recommended Practice, Society of Automotive Engineers, Inc., Warrendale, PA, p. 7 (1975)

2 University of Michigan, "Mechanics of Heavy-Duty Trucks and Truck Combinations, "University of Michigan - College of Engineering, Ann Arbor, MI, p. 291 (1986)

3 Taborek, Jaroslav J., "Mechanics of Vehicles," Machine Design, p. 14 (1957)

4 SAE J670d, "Vehicles Dynamics Terminology," SAE Recommended Practice, Society of Automotive Engineers, Inc., Warrendale, PA, p. 7 (1975)

5 SAE J670d, "Vehicle Dynamics Terminology," SAE Recommended Practice, Society of Automotive Engineers, Inc., Warrendale, PA, p. 7 (1975)

6 University of Michigan, "Mechanics of Heavy-Duty Trucks and Truck Combinations, "University of Michigan - College of Engineering, Ann Arbor, MI, pp. 294-295 (1986)

7 SAE J670d, "Vehicle Dynamics Terminology," SAE Recommended Practice, Society of Automotive Engineers, Inc., Warrendale, PA, p. 8 (1975)

8 Taborek, Jaroslav J., "Mechanics of Vehicles," Machine Design, p. 12 (1957)

9 University of Michigan, "Mechanics of Heavy-Duty Trucks and Truck Combinations, "University of Michigan - College of Engineering, Ann Arbor, MI, p. 287 (1986)

10 SAE J670d, "Vehicle Dynamics Terminology," SAE Recommended Practice, Society of Automotive Engineers, Inc., Warrendale, PA, p. 8 (1975)

11 Taborek, Jaroslav J., "Mechanics of Vehicles," Machine Design, p. 13 (1957)

12 Shigley, Joseph E., "Mechanical Engineering Design," Mcgraw-Hill, New York, NY, p. 169 (1977)

13 Shigley, Joseph E., "Mechanical Engineering Design," Mc Graw-Hill, New York, NY, pp. 170-171 (1977)

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University of Michigan, "Mechanics of Heavy-Duty Trucks and Truck Combinations," University of Michigan - College of Engineering, Ann Arbor, MI, (1986)

Taborek, Jaroslav J., "Mechanics of Vehicles," Machine Design, (1957)

Shigley, Joseph E., "Mechanical Engineering Design," McGraw-Hill, New York, NY. p. 169 (1977)

APPENDIX A

MONROE AUTO EQUIPMENT SHOCK ABSORBER TEST REPORT L013497

TABLE	STANDARD MTS SET-UP PROCEDURE FOR A.M. GENERAL HMMWV SHOCK ABSORBERS	REPORT #:
		PROJECT #:
		PAGE OF
		DATE:

HYDRAULIC RESISTANCE VALUES (MIDSTROKE)

LOAD THE S/A INTO THE MTS IN THE MIDSTROKE POSITION. USING A 1.50 in. STROKE, CYCLE THE S/A AT 0.10 Hz WITH THE HAVERSINE SIGNAL INPUT. ADJUST THE MTS SPAN SETTING UNTIL NEITHER THE RECOIL LOCK (STOP) OR COMPRESSION STOP CAN BE DETECTED ON THE OSCILLOSCOPE WAVEFORM. THE 2500 lb LOAD RANGE SHOULD BE USED FOR THIS MEASUREMENT.

RECOIL LOCK (STOP)

LOAD THE S/A INTO THE MTS IN THE MIDSTROKE POSITION, AND ZERO THE DISPLACEMENT INDICATOR OF THE MTS. RAISE THE CROSSHEAD OF THE MTS SLOWLY UNTIL THE S/A IS FULLY EXTENDED (METAL TO METAL). THE ZERO POINT OF THE MTS NOW CORRESPONDS TO THE FULLY EXTENDED POSITION. ACTIVATE THE HAVERSINE INVERT SIGNAL INPUT FUNCTION. ADJUST THE MTS TO A 1.50" STROKE USING THE 5.0 inch STROKE RANGE (30% FSD). USE THE 10,000 lb LOAD RANGE.

COMPRESSION STOP

LOAD THE S/A IN THE MTS IN THE MIDSTROKE POSITION, AND ZERO THE DISPLACEMENT INDICATOR OF THE MTS. AS DESCRIBED ABOVE, LOWER THE CROSSHEAD UNTIL THE S/A IS FULLY COMPRESSED (METAL TO METAL) TO SET THE ZERO POINT. ACTIVATE THE HAVERSINE SIGNAL INPUT FUNCTION, AND ADJUST THE MTS FOR A 1.50 inch STROKE (SEE ABOVE). USE THE 10,000 lb LOAD RANGE.

L013427

DISTRIBUTION:	PREPARED BY:
	APPROVED BY:

TABLE FRONT * 590327-D F-V DATA THIRD SAMPLE SUBMISSION (MAR 5'85)	REPORT #:
	PROJECT #:
	PAGE OF
	DATE:

HYDRAULIC RESISTANCE

	RECOIL			COMPRESSION		
CPM	30	85	170	30	85	170
FRONT 3 *	270	1030	1790	170	695	1000
FRONT 4 *	260	940	1620	153	625	920
AVERAGE	263	990	1715	160	650	955

RECOIL LOCK (CUT-OFF)

CPM	30	85	170	30	85	170
FRONT 3 *	1520	3550	5260			
FRONT 4 *	900	2380	4090			
AVERAGE	895	2750	4580			

COMPRESSION LOCK (CUT-OFF)

CPM	30	85	170	30	85	170
FRONT 3 *				2650	3065	3405
FRONT 4 *				3780	3995	4000
AVERAGE				3430	3673	3800

L013456

DISTRIBUTION: * - THIS DENOTES THOSE SAMPLES FORWARDED TO A.M. GENERAL FOR TESTING. ALL OTHERS RETAINED IN LAB.	PREPARED BY:
	APPROVED BY:

TABLE	REPORT #:
REAR #1 10597-D	?JECT #:
F-V DATA	PAGE OF
THIRD SAMPLE SUBMISSION (MAR 15 '85)	DATE:

HYDRAULIC RESISTANCE

	RECOIL			COMPRESSION		
CPM	30	85	170	30	85	170
REAR 3 *	385	1300	2725	250	815	1070
REAR 4 *	380	1410	2965	240	690	960
AVERAGE	371	1340	2740	250	706	980

RECOIL LOCK (CUT-OFF)

CPM	30	85	170	30	85	170
REAR 3 *	620	2540	4500			
REAR 4 *	1090	3500	5780			
AVERAGE	770	2790	4875			

COMPRESSION LOCK (CUT-OFF)

CPM	30	85	170	30	85	170
REAR 3 *				3700	3900	3990
REAR 4 *				3100	3390	3720
AVERAGE				3455	3745	3920

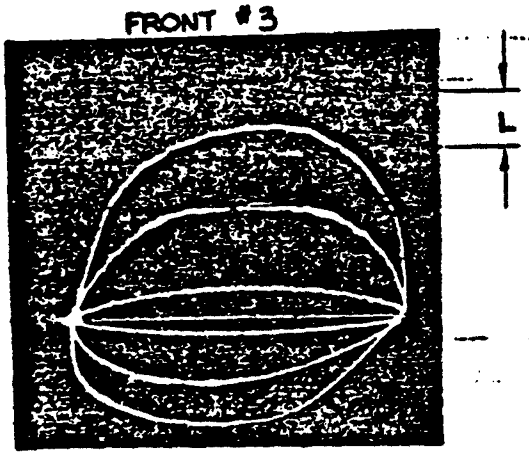
L0131159

A-5

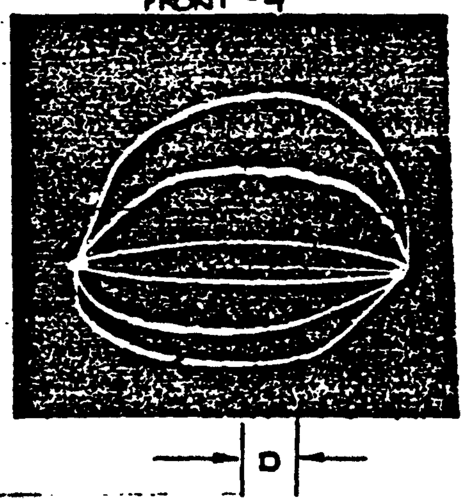
DISTRIBUTION: * - THIS DENOTES THOSE SAMPLES FORWARDED TO A.M. GENERAL FOR TESTING. ALL OTHERS RETAINED IN LAB.	PREPARED BY:
	APPROVED BY:

FIGURE FRONT 5590327-D MIDSTROKE (HYDRAULIC) VALUES	REPORT #:
	PR ECT #:
	PAGE OF
	DATE:

FRONT #3



FRONT #4



LOAD 500 lb/DIV , L

DISPLACEMENT 0.25 in/DIV , D

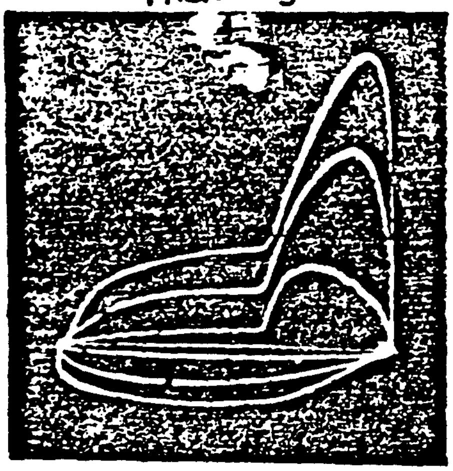
L013500

A-6

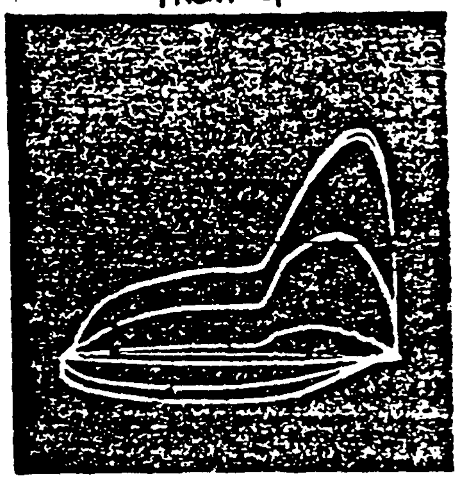
DISTRIBUTION: 30, 85, 170 CPM @ 1.5" STROKE HAVERSINE SIGNAL INPUT	PREPARED BY:
	APPROVED BY:

FIGURE FRONT 5590327-D RECOIL CUT-OFF VALUES	REPORT #: PROJECT #: PAGE OF DATE:

FRONT #3



FRONT #4



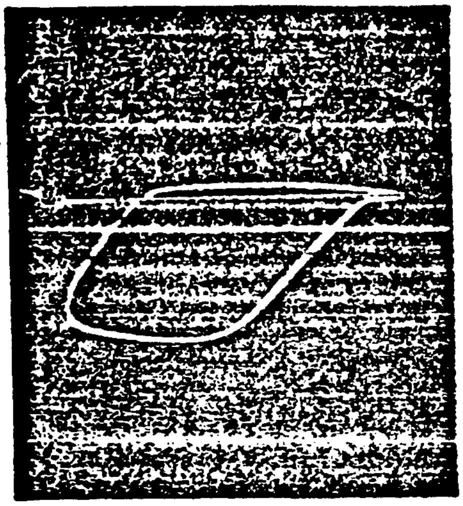
LOAD	1000	lb/DIV
DISPLACEMENT	0.25	in/DIV

L013501

DISTRIBUTION: 30, 85, 170 CPM @ 1.5" STROKE HAVERSINE SIGNAL INPUT INVERTED	PREPARED BY:
MTS ZERO POINT : S/A IN FULLY EXTENDED POSITION	APPROVED BY:

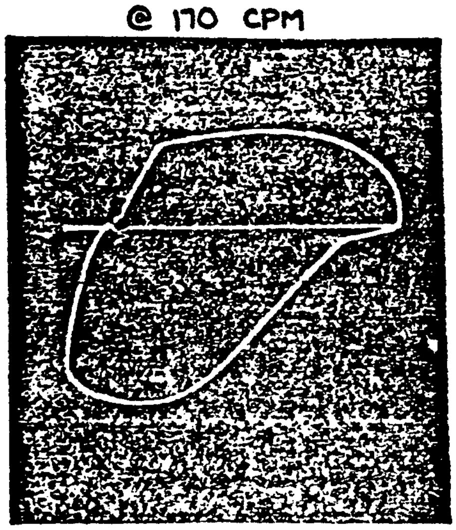
FIGURE	REPORT #:
FRONT 5590327-D	PROJECT #:
SAMPLE #3	PAGE OF
COMPRESSION CUT-OFF VALUES	DATE:

@ 30 CPM



@ 85 CPM

@ 170 CPM



LOAD 1000 lb/DIV
DISPLACEMENT 0.25 in/DIV

L013502

A-8

DISTRIBUTION: @ 1.5" STROKE HAVERSINE SIGNAL INPUT	PREPARED BY:
MTS ZERO POINT : S/A IN FULLY COLLAPSED POSITION	APPROVED BY:

FIGURE FRONT J590327-D SAMPLE #4 COMPRESSION CUT-OFF VALUES	REPORT #: PROJECT #: PAGE OF DATE:

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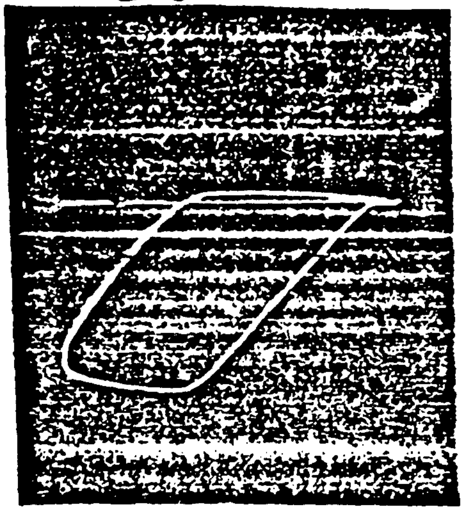
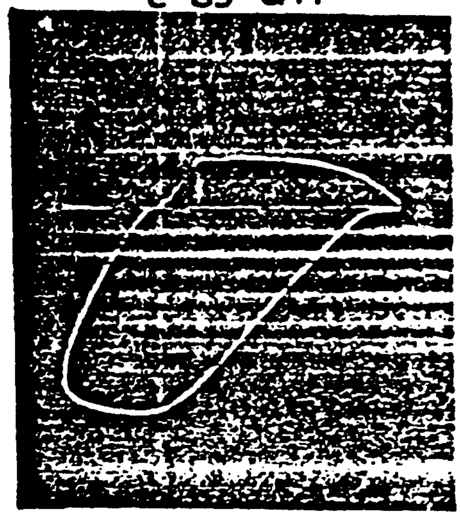
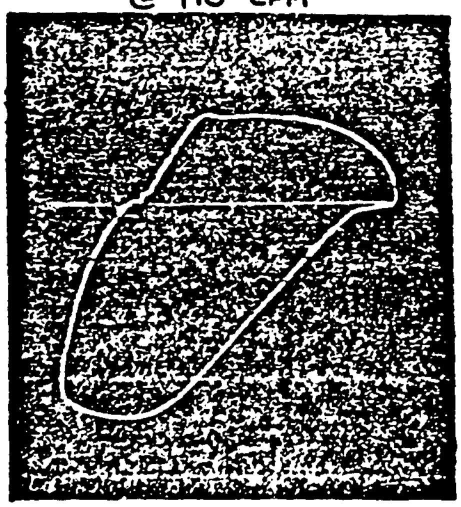


@ 85 CPM



@ 170 CPM



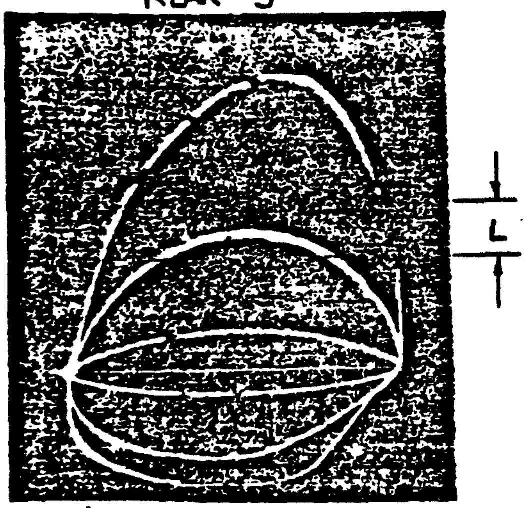
LOAD 1000 lb/DIV
DISPLACEMENT 0.25 in/DIV

L013583

DISTRIBUTION: @ 1.5" STROKE HAVERSINE SIGNAL INPUT	PREPARED BY:
MTS ZERO POINT : S/A IN FULLY COLLAPSED POSITION	APPROVED BY:

FIGURE REAR 5590597-D MIDSTROKE (HYDRAULIC) VALUES	REPORT #:
	PROJECT #:
	PAGE OF
	DATE:

REAR #3



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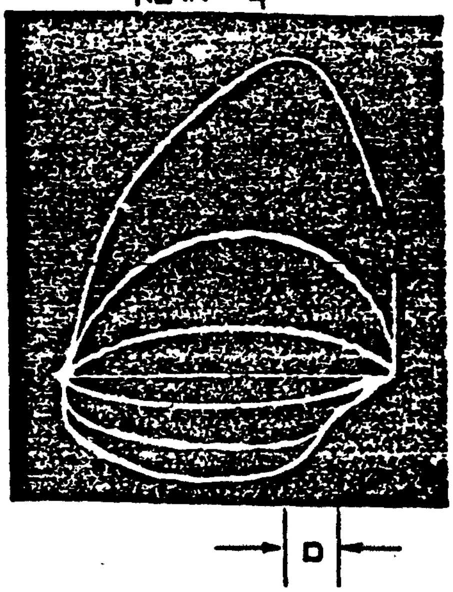


LOAD	500	L	lb/DIV
DISPLACEMENT	0.25	D	in/DIV

L013504

A-10

DISTRIBUTION: 30, 85, 170 CPM @ 1.5" STROKE HAVERSINE SIGNAL INPUT	PREPARED BY:
	APPROVED BY:

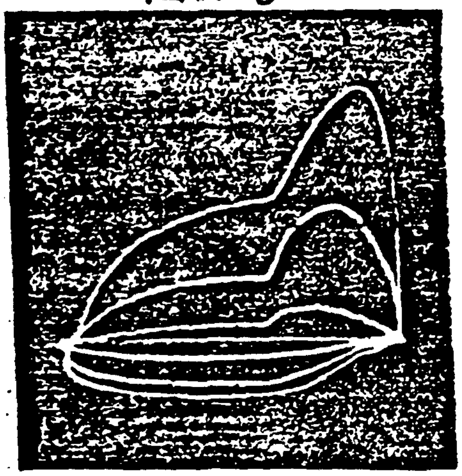
FIGURE

REAR 5[illegible]0597-D

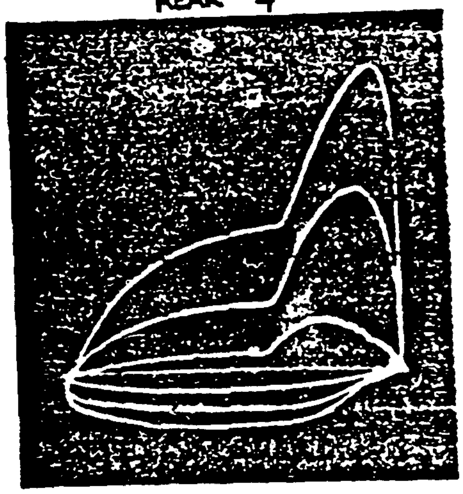
RECOIL CUT-OFF VALUES

REPORT #:	
P.. JECT #:	
PAGE	OF
DATE:	

REAR #3



REAR #4



LOAD 1000 lb/DIV

DISPLACEMENT 0.25 in/DIV

A-11

L013565

DISTRIBUTION: 30, 85, 170 CPM @ 1.5" STROKE
HAVERSINE SIGNAL INPUT INVERTED

MTS ZERO POINT : S/A FULLY EXTENDED POSITION

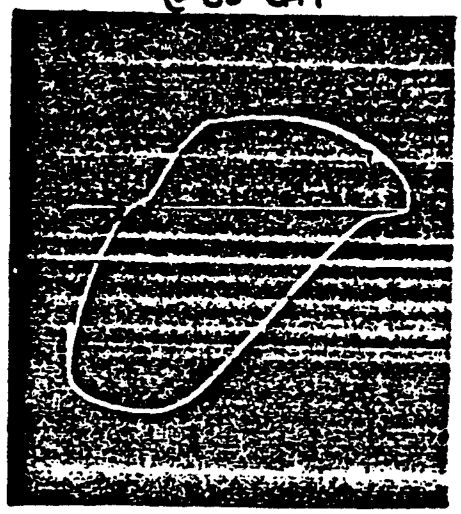
PREPARED BY:

APPROVED BY:

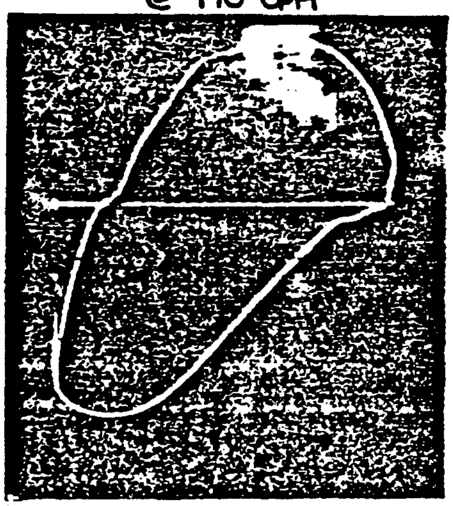
FIGURE	REPORT #:
REAR 5-10597-D SAMPLE # 3 COMPRESSION CUT-OFF VALUES	PROJECT #:
	PAGE OF
	DATE:

@ 30 CPM

@ 85 CPM



@ 170 CPM



LOAD 1000 lb/DIV
DISPLACEMENT 0.25 in/DIV

L013506

A-12

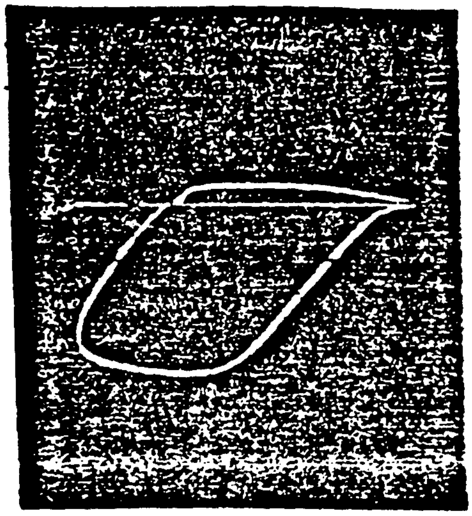
DISTRIBUTION: @ 1.5" STROKE HAVERSINE SIGNAL INPUT	PREPARED BY:
MTS ZERO POINT : S/A IN FULLY COLLAPSED POSITION	APPROVED BY:

FIGURE

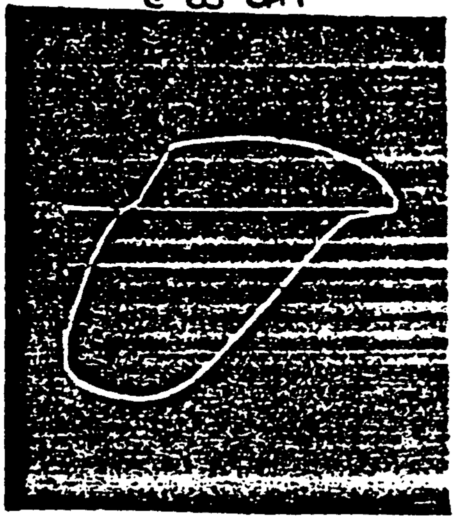
REAR 5_ /0597-D
SAMPLE # 4
COMPRESSION CUT-OFF VALUES

REPORT #:	
PROJECT #:	
PAGE	OF
DATE:	

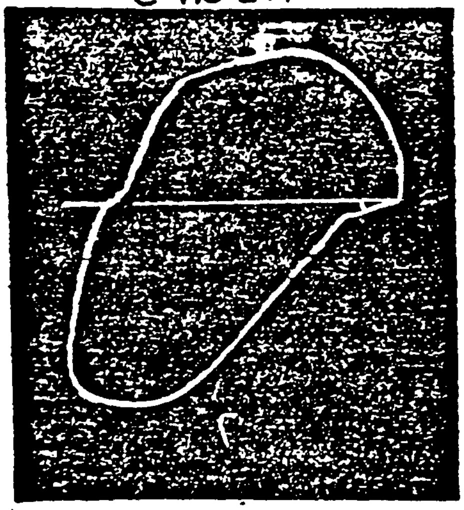
@ 30 CPM



@ 85 CPM



@ 170 CPM



F.6

LOAD 1000 lb/DIV
DISPLACEMENT 0.25 in/DIV

L013507

DISTRIBUTION: @ 1.5" STROKE HAVERSINE SIGNAL INPUT	PREPARED BY:
MTS ZERO POINT : S/A IN FULLY COLLAPSED POSITION	APPROVED BY:

APPENDIX B

UNIVERSITY OF MICHIGAN TRANSPORTATION INSTITUTE LETTER DATED JULY 23, 1985

UMTRI The University of Michigan Transportation Research Institute
2901 Baxter Road, Ann Arbor, Michigan 48109-2150

July 23, 1985

Mr. Roger Wehage

US ARMY TACOM
Warren, MI

Dear Roger:

The purpose of this letter is to present the results of a program of parameter measurements which UMTRI has recently conducted on the HMMWV 1-1/4 ton vehicle.

The program included the measurement of weight, center of gravity position and principle moments of inertia of the total vehicle. Vertical spring rate and Coulomb friction, roll steer and aligning moment steer were measured for the rear suspension. These, plus the influence of the auxiliary roll stiffness device, were measured for the front suspension. (The rear suspension has no "anti-sway bar".) Overall steering ratio was also measured.

Results of the inertia testing program are presented in tabular form on two enclosed sheets.

Suspension measurement results are presented graphically on eight enclosed sheets. Some comments on the suspension data follow.

1) Vertical spring rate and Coulomb friction.

At the nominal wheel load of 1500 lb, the front suspension shows a vertical spring rate of about 242 lb/in and Coulomb friction of about 106 lb. Front spring rate varies with load, however.

The rear suspension shows relatively constant spring rate of about 368 lb/in and Coulomb friction of about 112 lb.

For both front and rear, suspension travel is limited by shock absorber stroke in both rebound and compression. These limits are clearly apparent in the data.

2) Auxilary roll stiffness.

Only the front suspension is equipped with an auxiliary roll stiffener. Vertical rate data with the device in play show a rate of 296 lb/in at 1500 lb wheel load. Comparing this with the base rate yields an auxiliary vertical rate of 54 lb/in. Given a 72 inch track width, this is equivilent to 2443 in-lb/deg of auxiliary roll stiffness.

$\text{suspension roll} = \frac{1 \text{ in}}{\text{ArcTan}\left(\frac{1}{72}\right)} = 1.2567 \text{ in/deg}$

$54 \text{ lb/in} \times \frac{72}{2} \text{ in} \times 1.2567 \frac{\text{in}}{\text{deg}} = 2443 \text{ in-lb/deg}$

3) Steer properties, front suspension.

Overall steering system ratio was measured and is presented graphically. As per our telephone conversation, steer gear box ratio was not measured.

Front aligning moment compliance steer shows the typical "S" shape indicating a lash about zero moment and spring-like behavior at non-zero moments. This steering system shows about 1/2 deg lash and a rate of about 2200 in-lb/deg. This compliance steer would appear to be the strongest suspension steer influence on the vehicle.

Front roll steer data appears to indicate negligible roll steer on center. The response appears to be dominated by "wondering" within the steering system lash.

4) Steer properties, rear suspension.

Aligning moment steer at the rear is characterized by a rather consistent rate of about 14,300 in-lb/deg.

Unlike the front, roll steer at the rear is significant ranging from about -.05 deg/deg to about -.20 deg /deg depending on load and roll position. This variation reflects the non-linear quality of the suspension linkage. Roll steer measurements were made on the right rear wheel. Since the suspension is symmetric, the left wheel behavior will be similar with the polarity of both steer angle and roll angle axes reversed.

If I can be of further assistance, please call. (I will be on vacation until Aug. 13.)

Sincerely,

C.B. Winkler

INERTIAL PROPERTIES TEST RESULTS*

Weight	5860 lbs
Center of Gravity Position	
Aft of Front Axle	61.8 inches
Above Ground	32.5 inches
Moments of Inertia	
Pitch	41,300 in-lb-sec**2
Yaw	52,300 in-lb-sec**2
Roll	13,900 in-lb-sec**2

*Vehicle tested with full fuel tanks, otherwise empty.

UMTRI PITCH PLANE INERTIAL PROPERTIES TEST

TEST NO.:

DATE: [illegible] TIME: Am OPERATOR: [illegible]

I. VEHICLE ID

MANUFACTURER: Am General WHEELBASE: 130

MODEL NO.: HMMWV - Truck SERIAL NO.:

II. BODY ID

MANUFACTURER: DESCRIPTION:

MODEL NO.: SERIAL NO.:

III. VEHICLE CONDITION

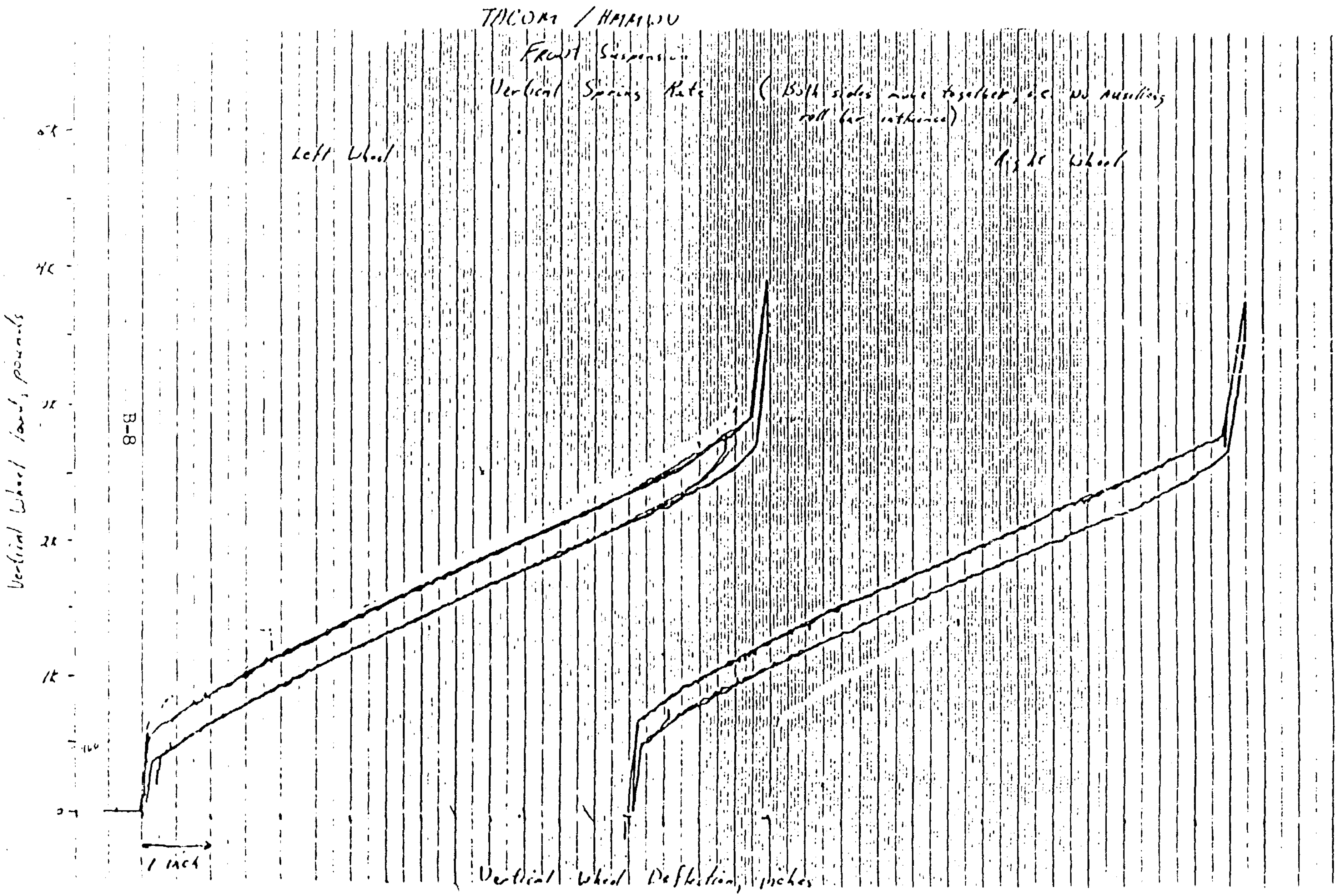
GAS: Full LOADING: Empty

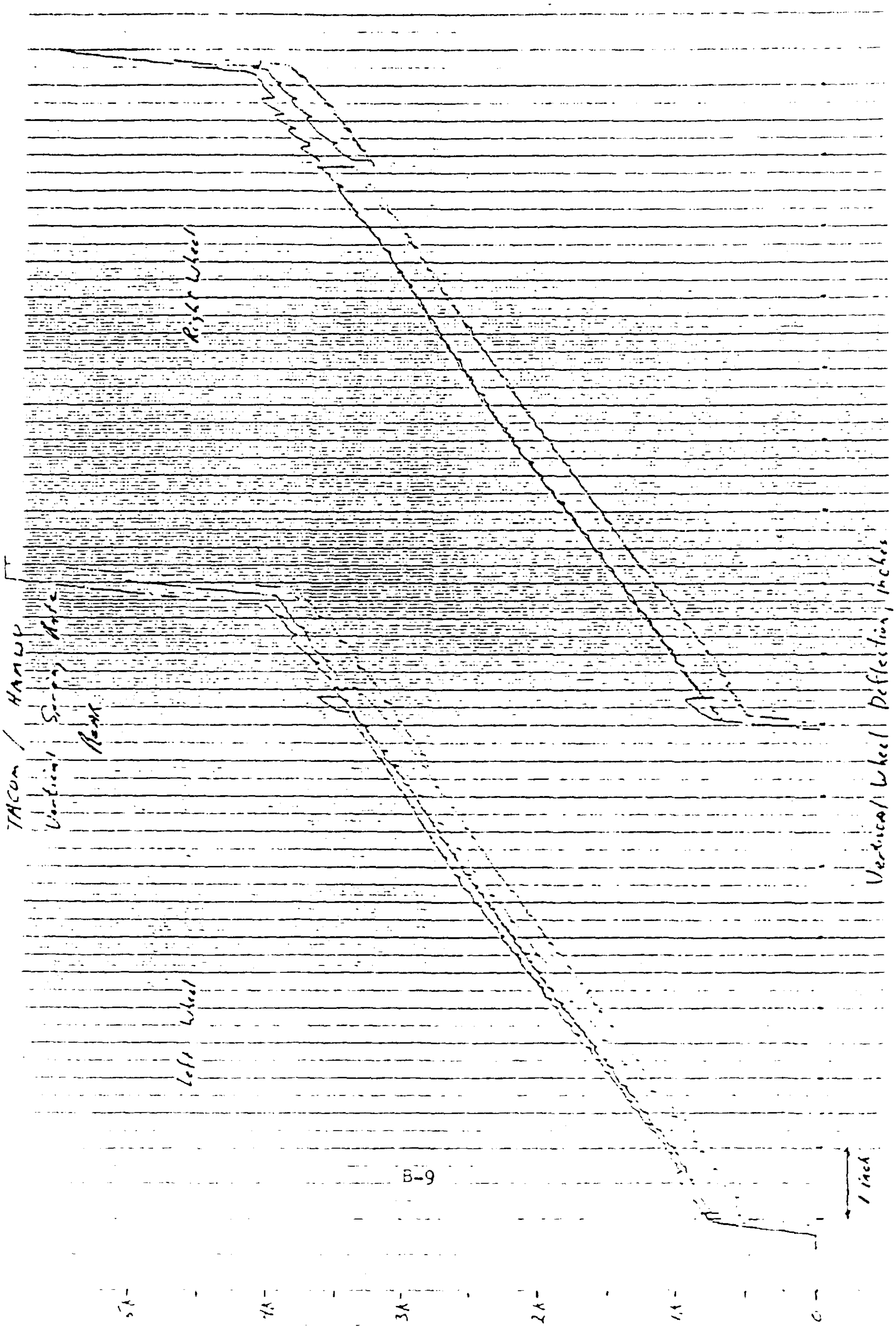
IV. RESULTS

	TEST 1	2	3	AVG
CG POSITION (INCHES)				
AFT OF FRONT AXLE	61.79	61.8	61.8	61.8
EXPECTED ERROR	.156	.155	.154	
STANDARD DEVIATION				5E-03
HEIGHT ABOVE VEHICLE REFERENCE POINT*	14.2	14.15	14.17	14.17
EXPECTED ERROR	.387	.393	.413	
STANDARD DEVIATION				.021
HEIGHT ABOVE GROUND				32.47
PITCH MOMENT OF INERTIA ABOUT CG (IN-LB-SEC^2)	40617	42577	40656	41283
EXPECTED ERROR	1333	1368	1333	
STANDARD DEVIATION				915

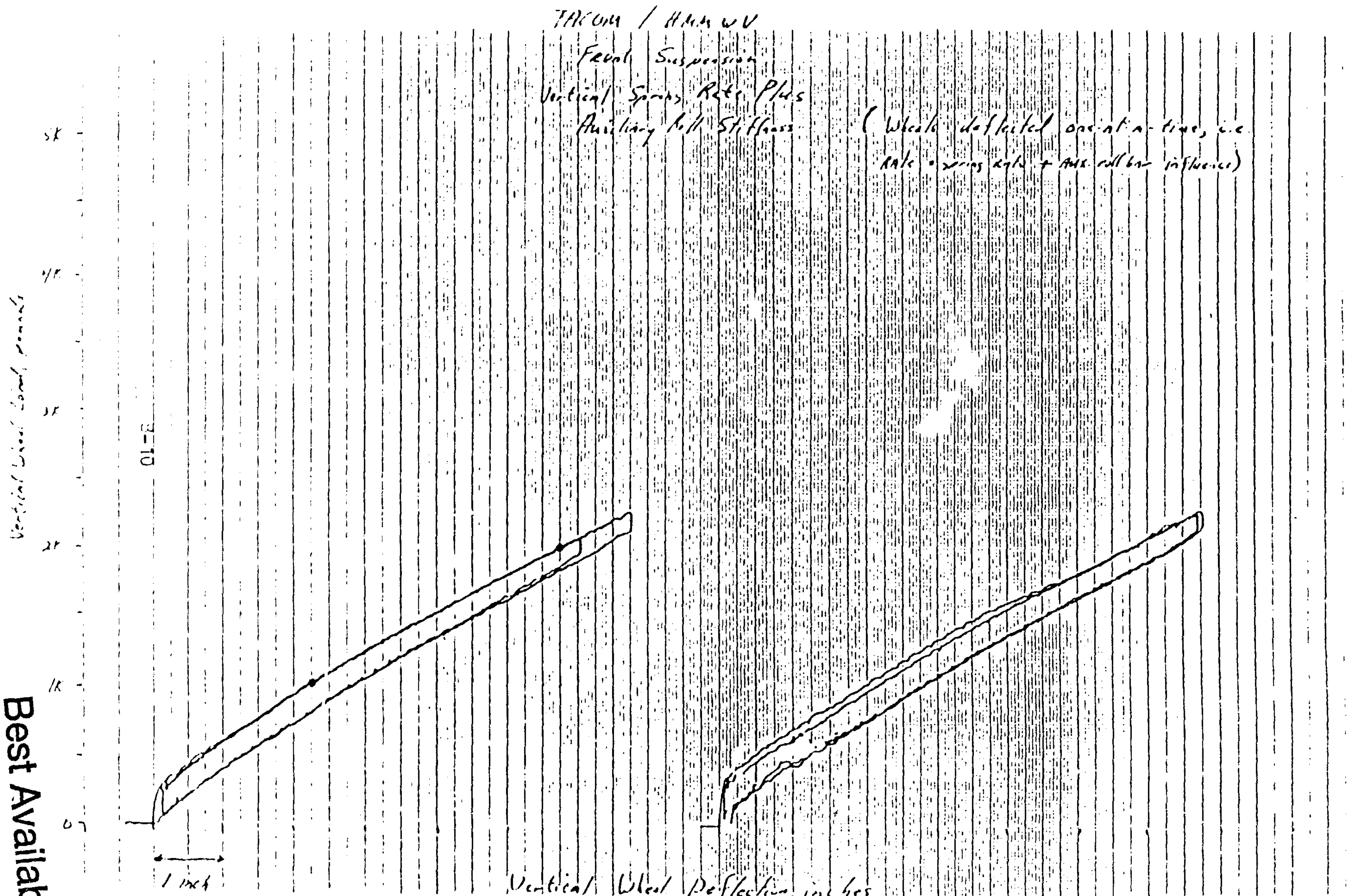
WEIGHT: 5360 LBS

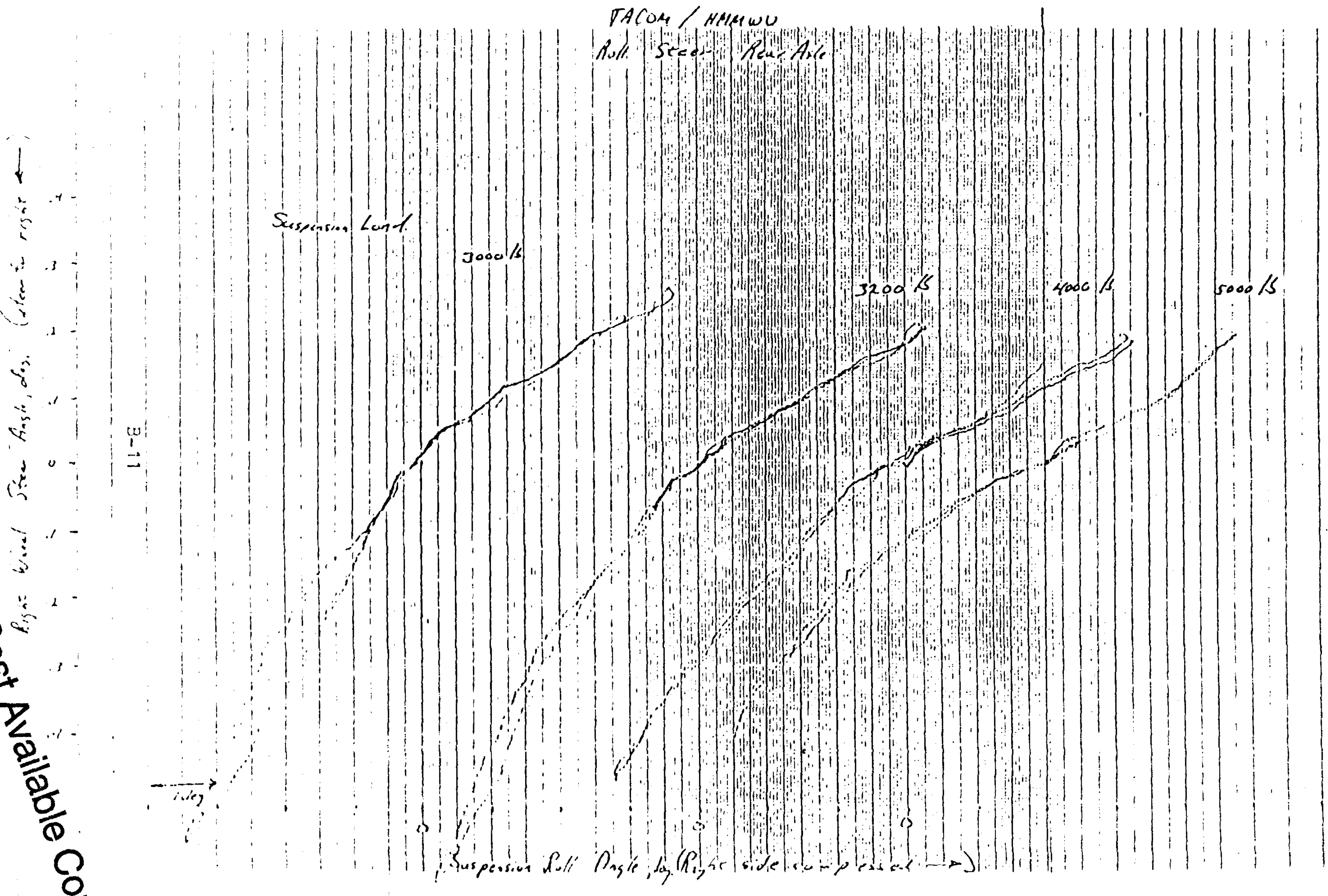
* REFERENCE POINT IS LOWER FACE OF FRAME AT CG

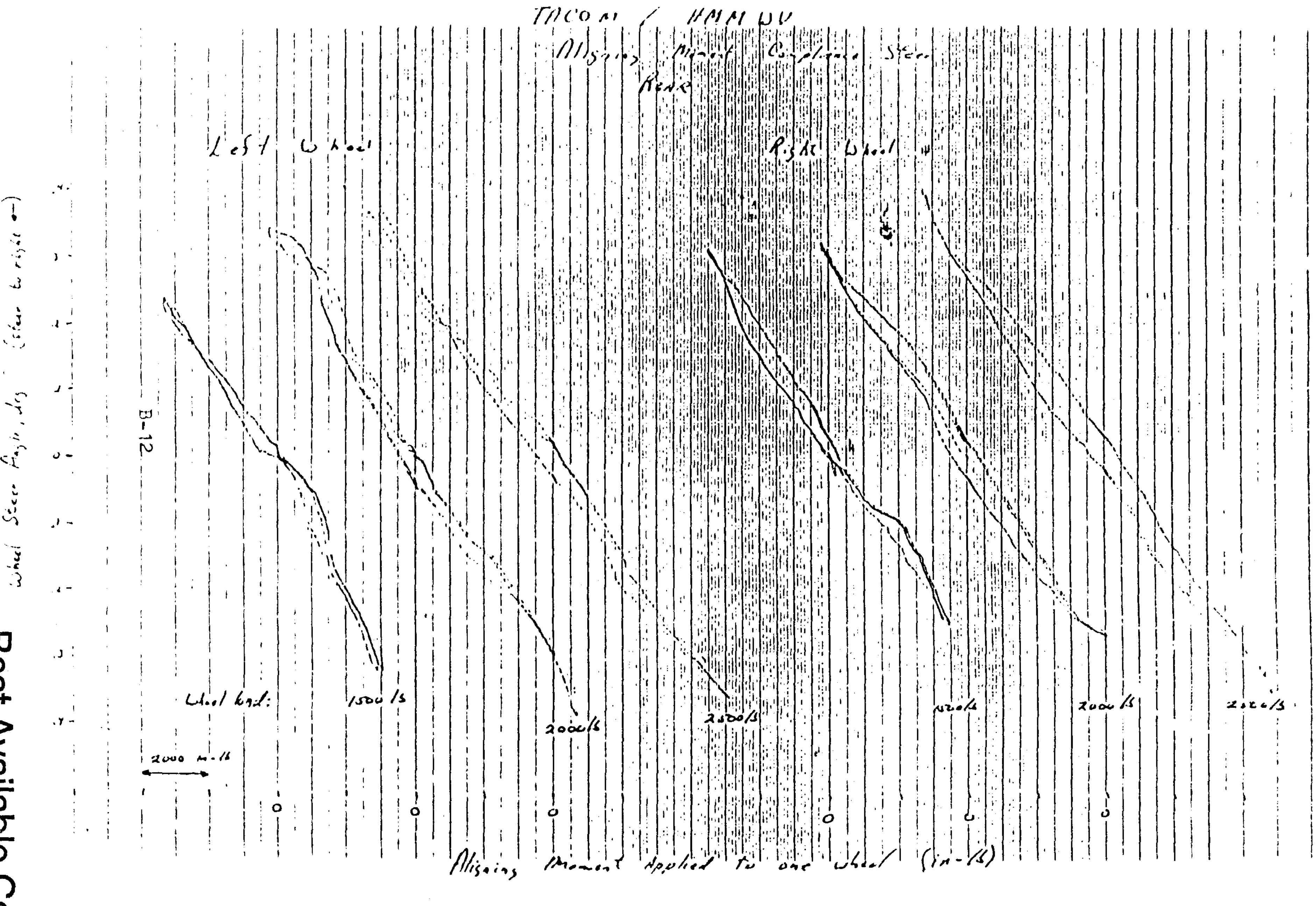

TACOMA / HMMWV
Front Suspension
Vertical Spring Rate (Both sides move together, i.e. no auxiliary roll bar influence)
Left Wheel
Right Wheel
Vertical Wheel load, pounds
5K
4K
3K
2K
1K
0
Vertical Wheel Deflection, inches
1 inch



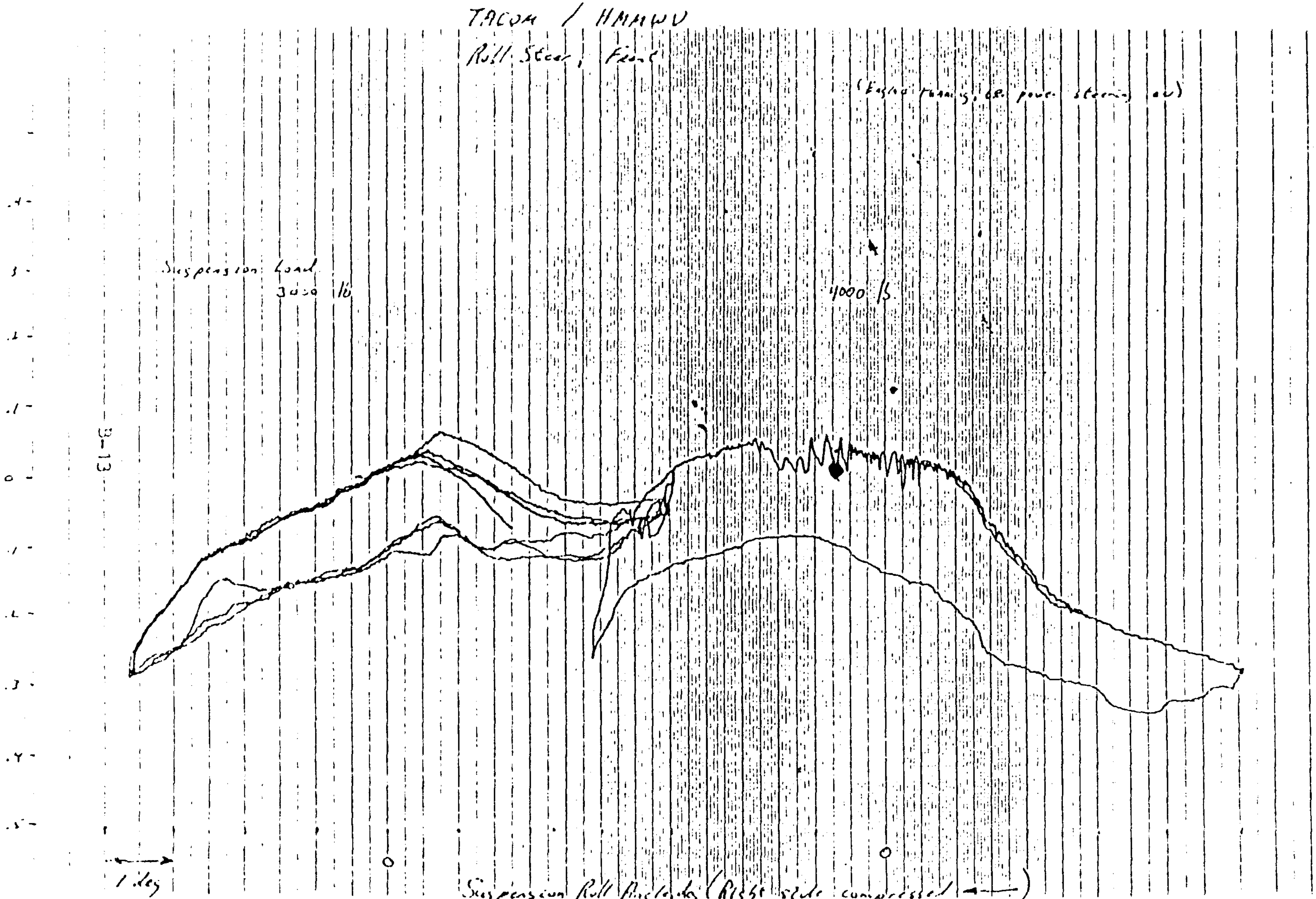
Vertical Spring Rate
Rear
Right Wheel
Left Wheel
Vertical Wheel Deflection, Inches
1 inch
0
1K
2K
3K
4K
5K
Vertical Wheel Load, pounds

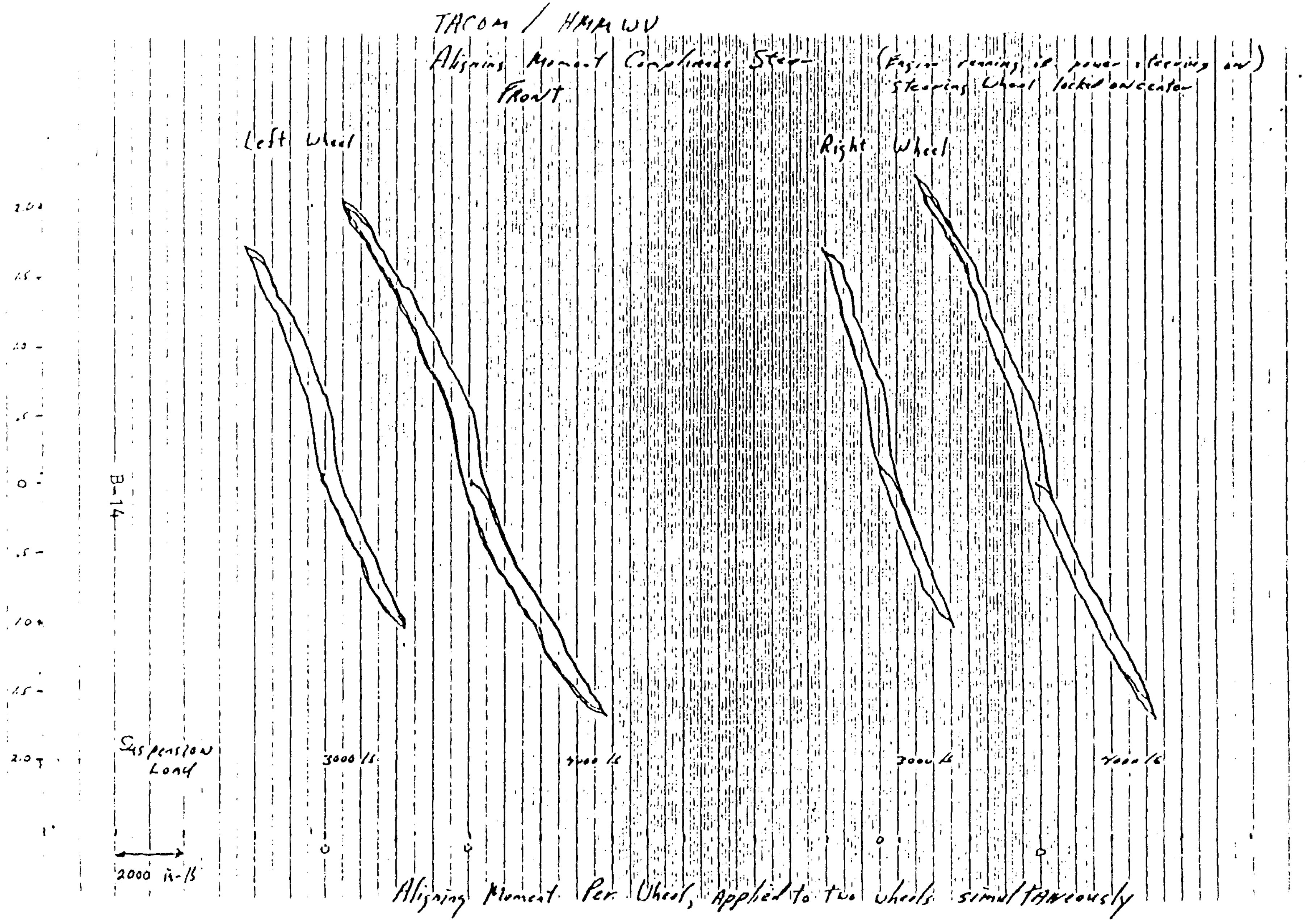

TACOM / HMMWV
Front Suspension
Vertical Spring Rate Plus
Auxiliary Roll Stiffness
(Wheels deflected one-at-a-time, i.e.
Rate = spring rate + Aux. roll bar influence)
5K
4K
3K
2K
1K
0
Vertical Wheel Load, pounds
1 inch
Vertical Wheel Deflection, inches

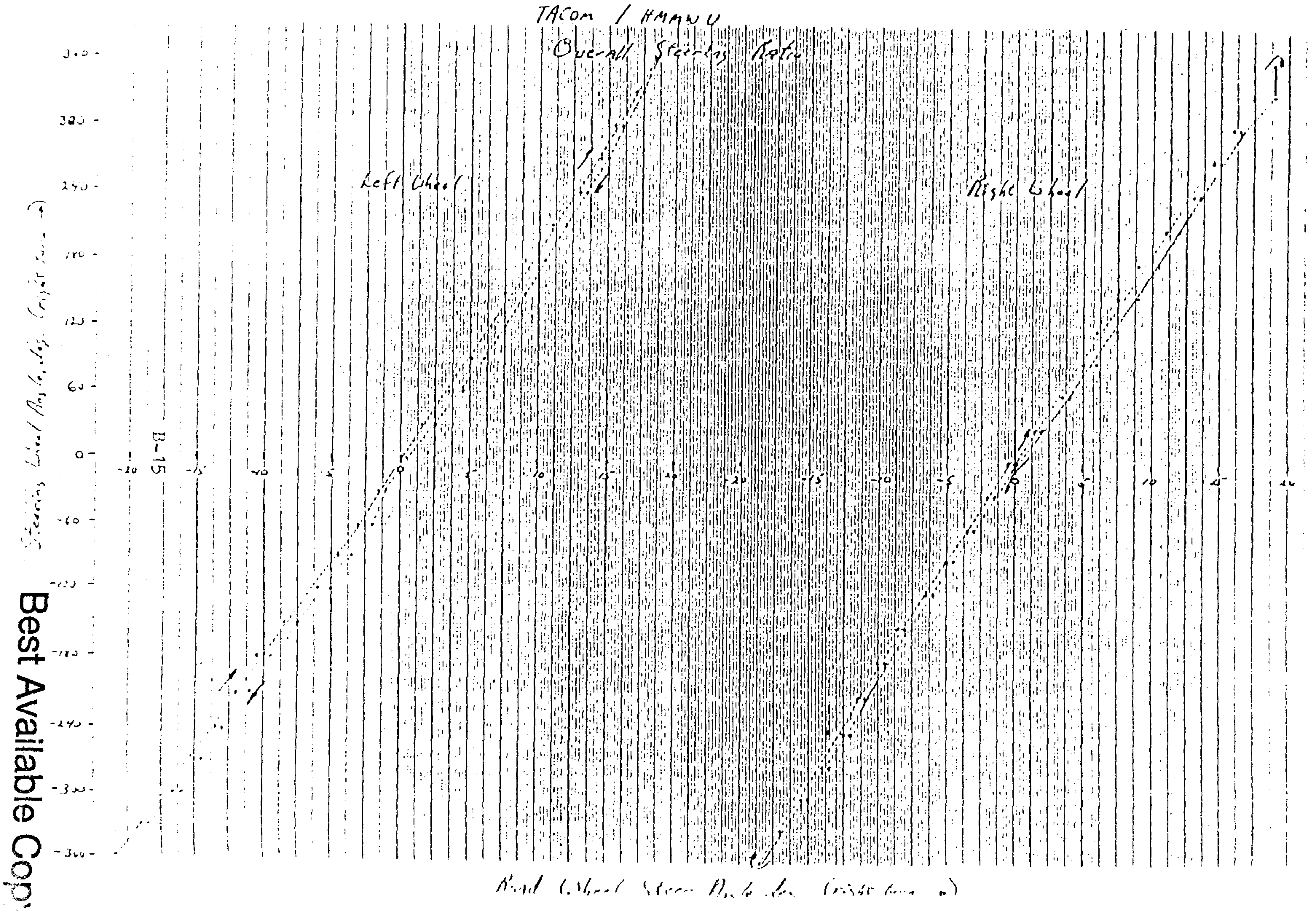

TACOM / HMMWV
Roll Steer Rear Axle
Suspension Load
3000 lb
3200 lb
4000 lb
5000 lb
Right Wheel Steer Angle, deg. (steer to right ←)
Suspension Roll Angle, deg (Right side compressed →)
1 deg



TACOM / HMMWV
Aligning Moment Compliance Steer
Left Wheel
Right Wheel
Wheel load:
1500 lb
2000 lb
2500 lb
2000 lb
2000 in-lb
Aligning Moment Applied to one Wheel (in-lb)
Wheel Steer Angle, deg (steer to right →)


TACOM / HMMWV
Roll Steer, Front
Suspension Load
3000 lb
4000 lb
1 deg
Suspension Roll Angle, deg (Right side compressed)


TACOM / HMMWV
Aligning Moment Compliance Step - (Engine running, ie power steering on)
Steering Wheel locked on center
FRONT
Left Wheel
Right Wheel
3000 lb
4000 lb
3000 lb
4000 lb
Suspension Load
2000 ft-lb
Aligning Moment Per Wheel, Applied to two wheels simultaneously
2.0
1.5
1.0
.5
0
.5
1.0
1.5
2.0
Road Wheel Steer Angle, deg (← steer to right)


TACOM / HMMWV
Over-all Steering Ratio
Left Wheel
Right Wheel

Side Force, lbs.

Goodyear Wrangler R/T II
36x12.5-16.5 LT LR:C

Camber Angle, deg	Slip Angle, deg -1	0	1	2	4	8	16
-10		-53			-355	-435	-454
-5		-23			-299	-386	-437
-2		-5					
0	86 / 91	-5 / 2	-86 / -83	-163 / -152	-277 / -265	-378 / -357	-424 / -409
2		8					
5		24			-252	-343	-419
10		47			-247	-385	-454

Vertical load 500 lb

Inflation Press. 24 psi

Side Force, lbs

Goodyear Wrangler A/T II
36×12.5-16.5 LT LRC

Camber Angle, deg	Slip Angle, deg -1	0	1	2	4	8	16
-10		-122			-548	-672	-714
-5		-67			-500	-629	-686
-2		-18					
0	145 / 148	-2 / 6	-141 / -137	-262 / -247	-432 / -417	-587 / -567	-653 / -632
2		23					
5		66			-409	-582	-671
10		108			-352	-563	-685

Vertical load 800 lb

Inflation press. 24 psi

Side Force, lb.

Goodyear Wrangler R/T II
36x12.5-16.5 LT LRC

Camber Angle, deg	Slip Angle, deg: -1	0	1	2	4	8	16
-10		-378			-1114	-1331	-1450
-5		-227			-1042	-1295	-1426
-2		-109					
0	280	3	-281	-522	-890	-1228	-1389
	290	9	-274	-500	-871	-1203	-1367
2		88					
5		212			-657	-1072	-1324
10		327			-562	-960	-1261

Vertical load 1700 lb

Inflation press. 24 psi

Side Force, lb

Goodyear Wrangler R/T II
36×12.5-16.5 LT LR:C

Camber Angle, deg	Slip Angle, deg: -1	0	1	2	4	8	16
-10		-574			-1477	-1887	-2133
-5		-296			-1292	-1763	-2059
-2		-138					
0	311	-9	-315	-591	-1062	-1691	-1970
0	334	1	-311	-515	-1022	-1569	-1946
2		104					
5		271			-753	-1373	-1830
10		507			-498	-1179	-1723

Vertical load 2600 lb

Inflation press. 24 psi

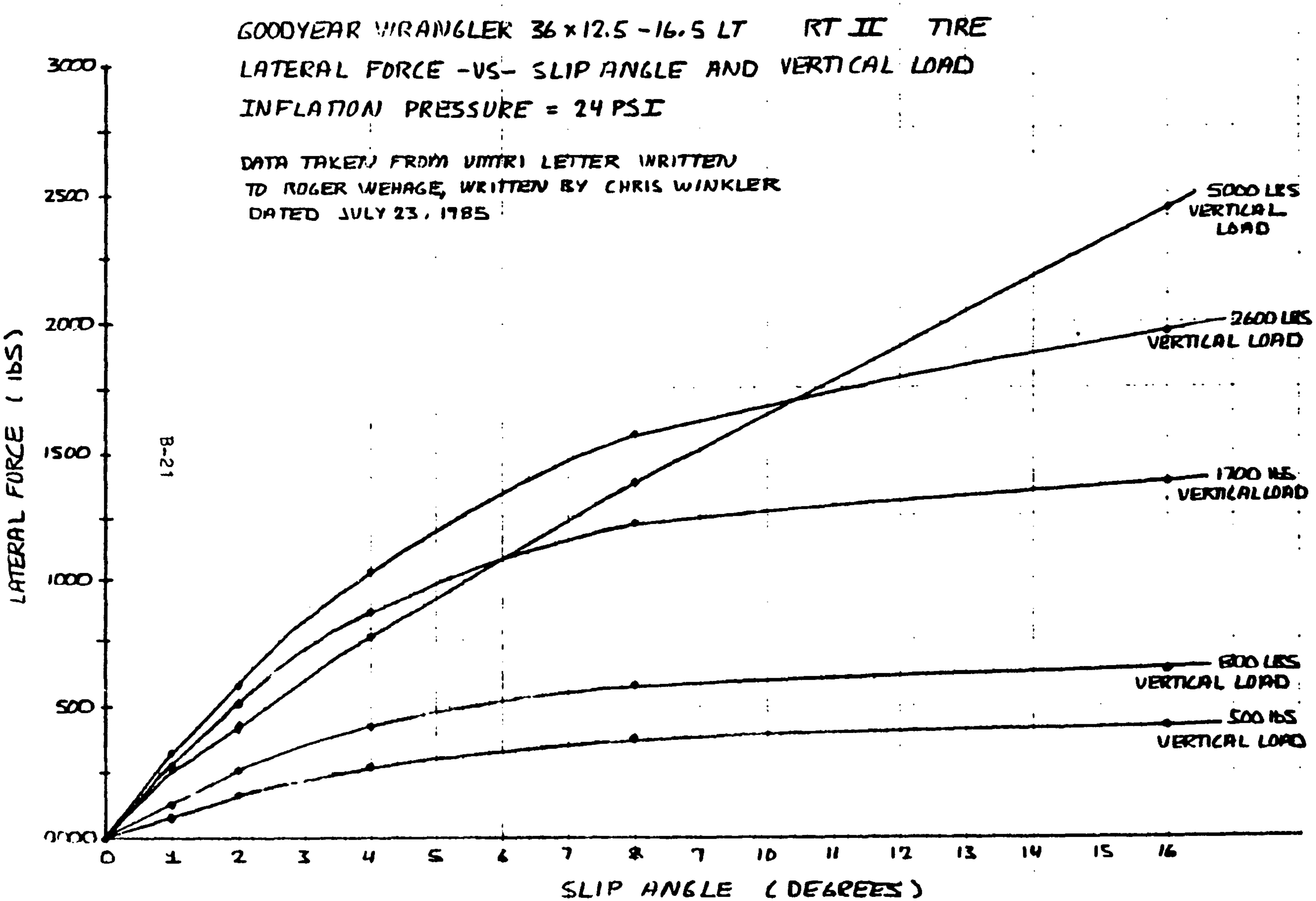
Side Force, lb.

Goodyear Wrangler RT II
36x12.5-16.5 LT LR...

Camber Angle, deg	Slip Angle, deg: -1	0	1	2	4	8	16
-10		-684			-1253	-1782	-2742
-5		-340			-1041	-1623	-2605
-2		-149					
0	167	-6	-198	-391	-754	-1403	-2476
	212	-1	-251	-434	-748	-1392	-2418
2		129					
5		346			-447	-1166	-2250
10		651			-151	-890	-2191

Vertical load 5000 lb

Inflation press. 24 psi


GOODYEAR WRANGLER 36 x 12.5 - 16.5 LT RT II TIRE
LATERAL FORCE -VS- SLIP ANGLE AND VERTICAL LOAD
INFLATION PRESSURE = 24 PSI
DATA TAKEN FROM UMTRI LETTER WRITTEN
TO ROGER WEHAGE, WRITTEN BY CHRIS WINKLER
DATED JULY 23, 1985
5000 LBS VERTICAL LOAD
2600 LBS VERTICAL LOAD
1700 LBS VERTICAL LOAD
800 LBS VERTICAL LOAD
500 LBS VERTICAL LOAD
LATERAL FORCE (lbS)
3000
2500
2000
1500
1000
500
0000
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
SLIP ANGLE (DEGREES)

APPENDIX C

GOODYEAR TIRE DATA

GOODYEAR TECHNICAL CENTER — AKRON

AKRON, OHIO 44316-0001

July 21, 1987

AM General Division
LTV Aerospace & Defense Company
11900 Hubbard Drive
PO Box 3330
Livonia, MI 48151-3330

Attention: R J Fanco

Subject: <u>36X12.50-16.5 LT Data for TACOM</u>

Dear Mr Fanco,

You requested through our Detroit office, the following technical data for the Bias HMMWV tire.

1. <u>Tire Damping Coefficient</u>

   We do not have actual data for this tire but have included three statements from available publications that should be applicable.

   "The tire acts as a linear spring to cushion shocks to the vehicle and to absorb impact loads. Unfortunately, the tire is not an effective damping device. Eliminating the adverse effects of bounce magnitude and frequency remains a function of the vehicle suspension system."

   "While the exact nature of tire damping is speculative, it is measurable and has proven to be a very small value when determined for a rolling tire. Values ranging from 1 to 20 lb-sec/in have been noted."

   "The damping coefficient (Zeta) for a bias truck tire (10.00-20) over the range of conditions tested ranged from 0.012 to 0.026."

2. **Tire Coefficient of Friction**

Concrete	dry	.7-.9
"	wet	.5-.7
Bituminous	dry	.6-.8
"	wet	.4-.7
Gravel, firm		.4-.7
Med. Soft Soil		.3-.5
Soft Loose Soil		.2-.4
Sand		.2-.3
Ice, Packed Snow		.05-.2
Mud		.1-.4
Steel	dry	.52
"	wet	.44

3. **Tire Normal Force Displacement Curve**

Load/Deflection Curve MD-319527 is attached.

4. **Tire Tangential Force Displacement Curve**

Both a tangential and lateral load/deflection curve of the 36X12.50-16.5 LT Wrangler R/T II are attached.

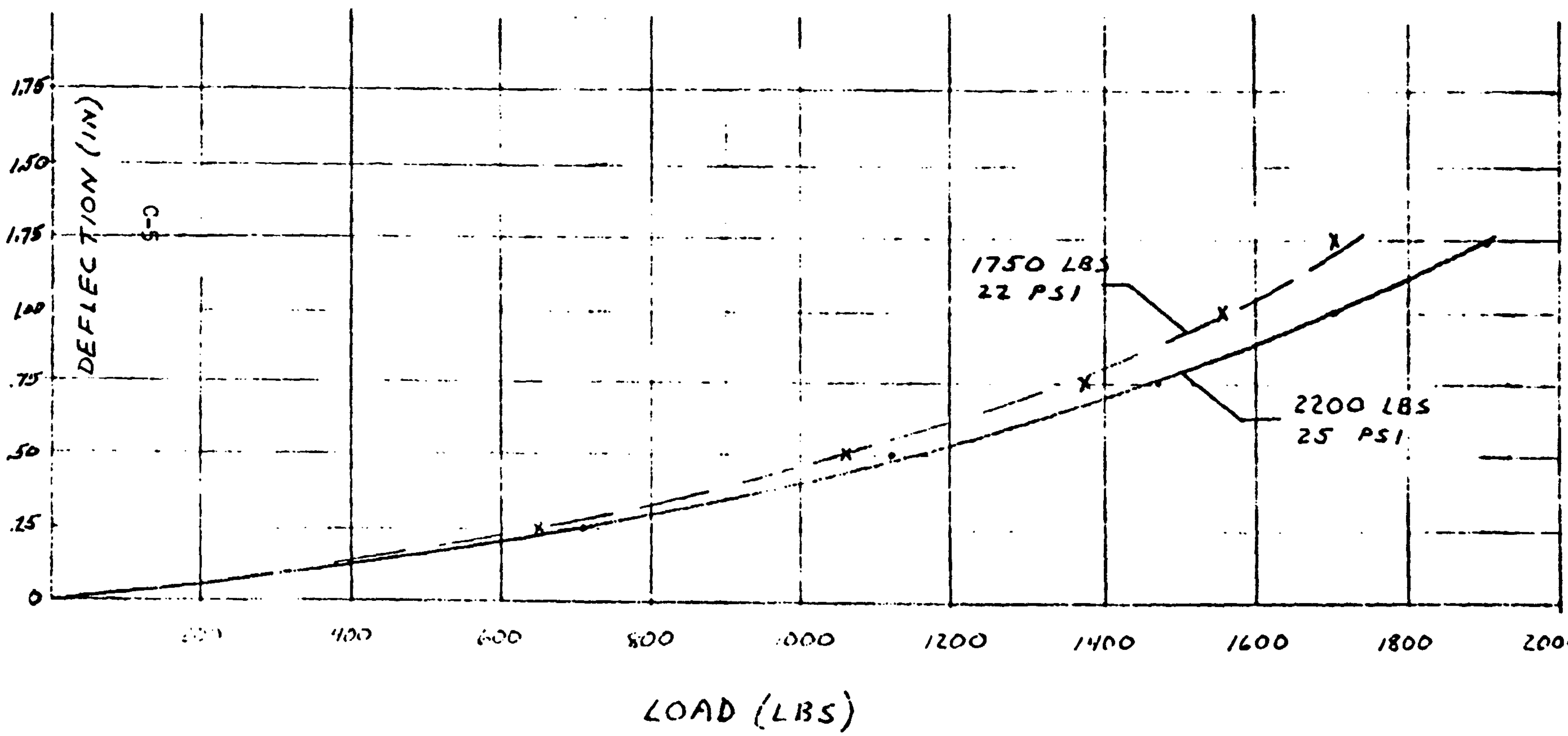
H R Vermie
Military Tire Applications

jfy

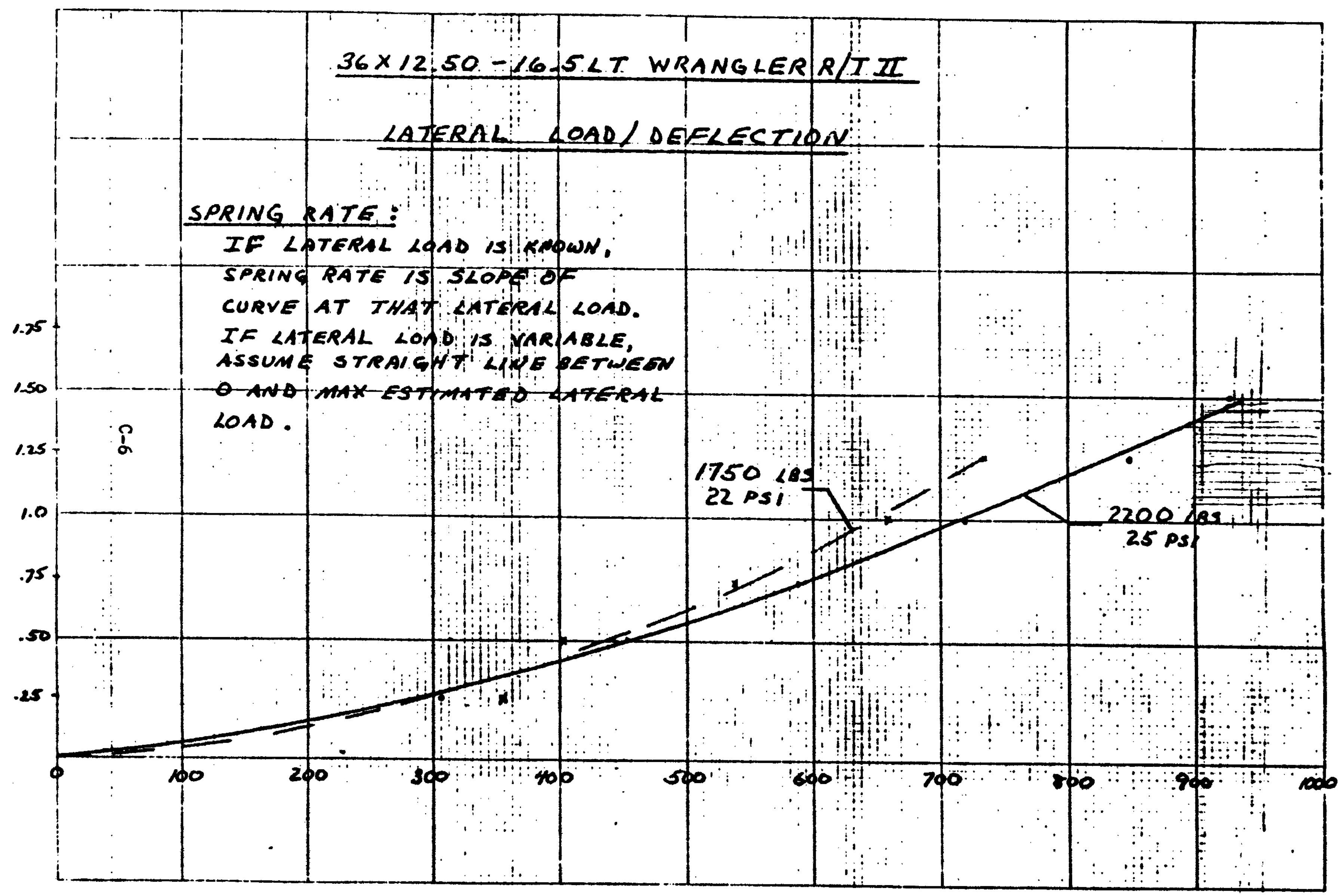
Attachments

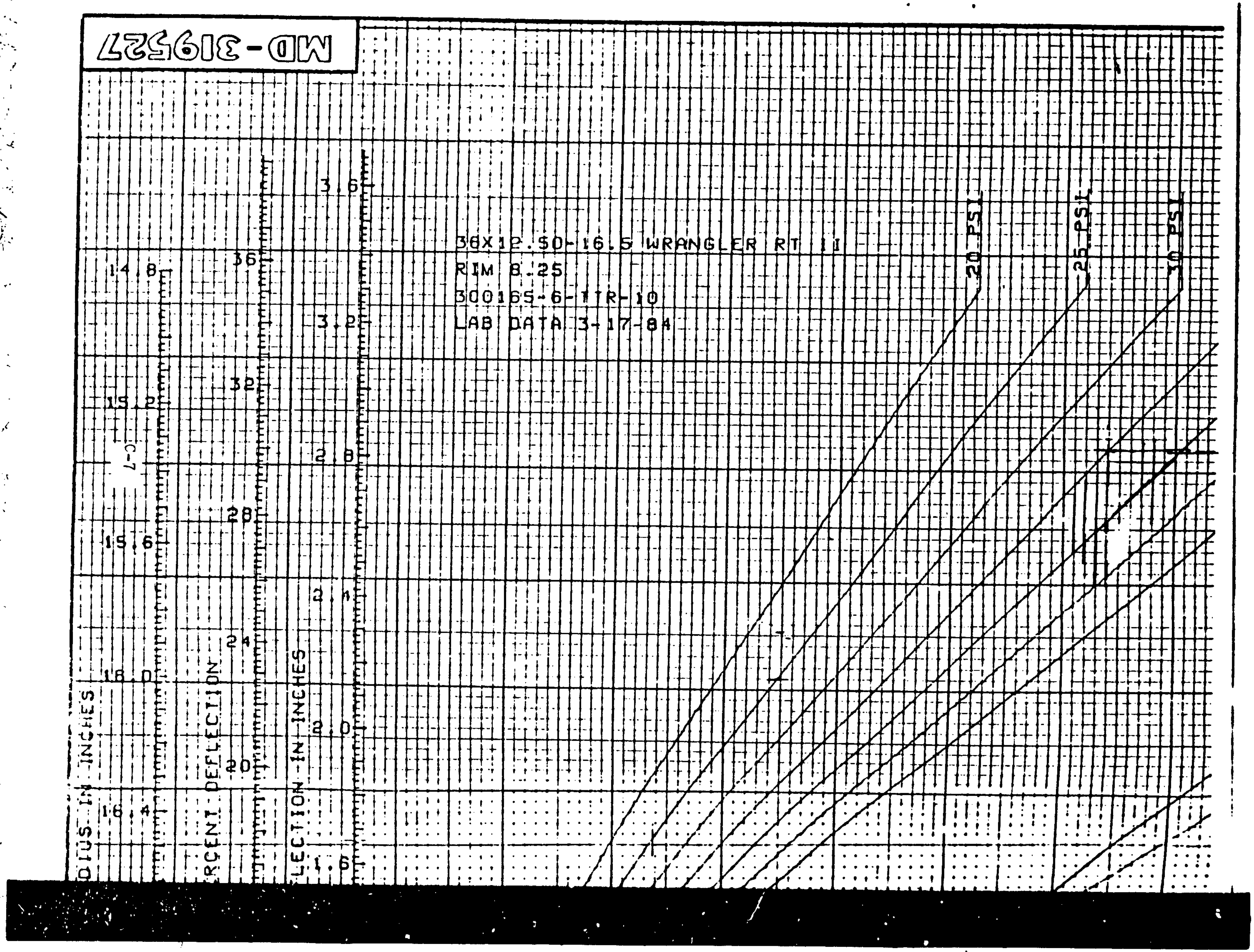
36 X 12.50-16.5LT WRANGLER R/T II

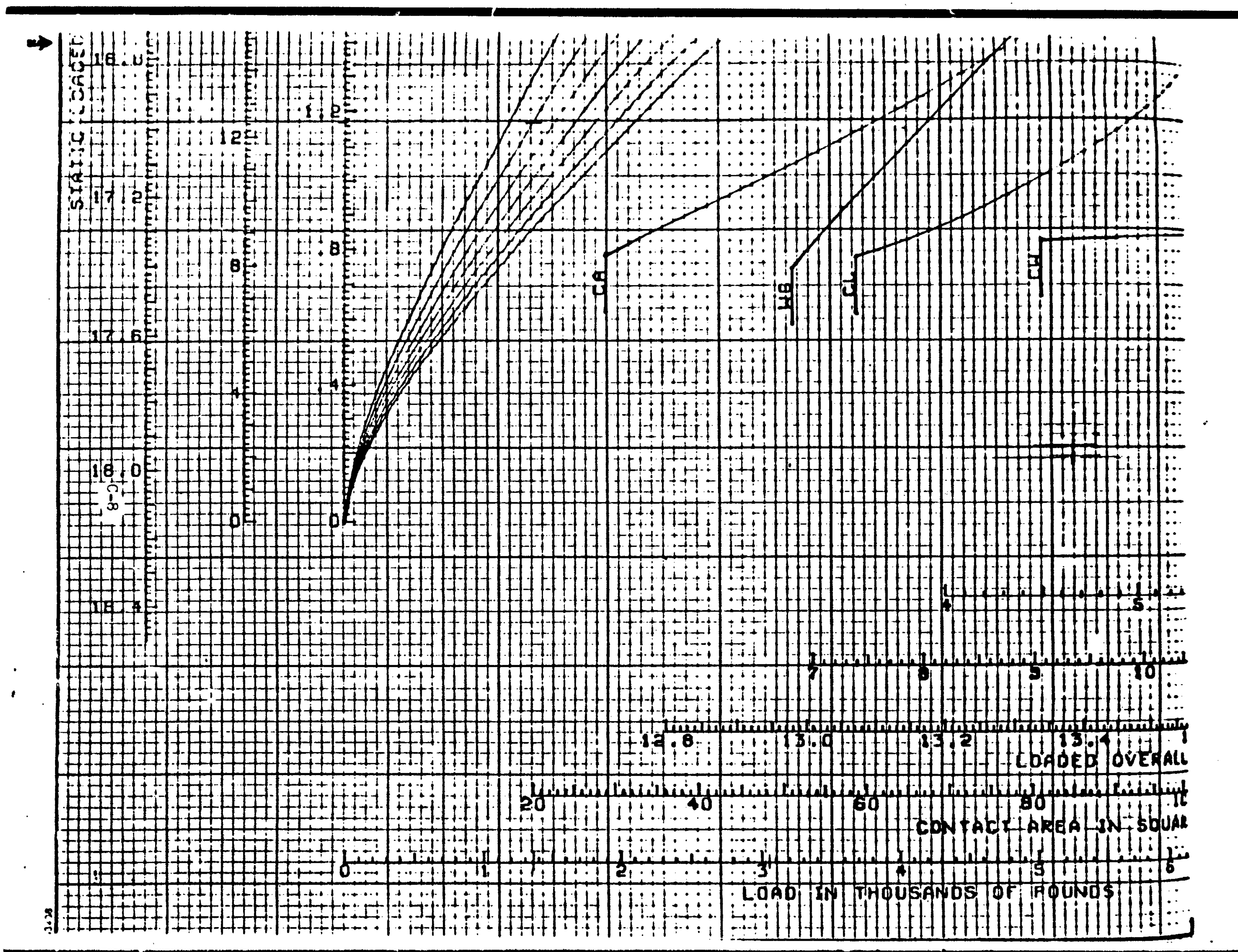
TANGENTIAL LOAD/DEFLECTION



[redacted]

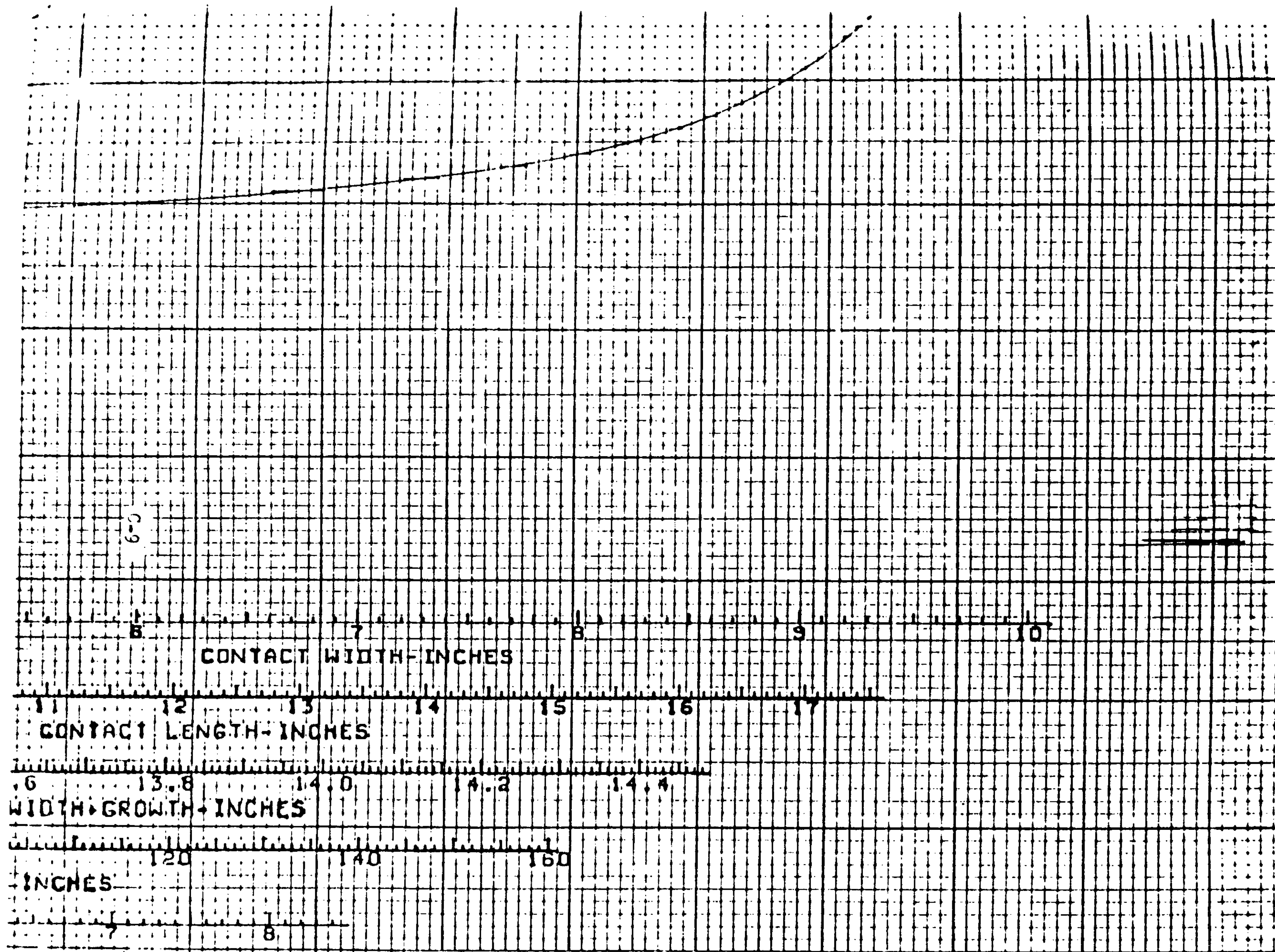

36 X 12.50 - 16.5 LT WRANGLER R/T II
LATERAL LOAD / DEFLECTION
SPRING RATE :
IF LATERAL LOAD IS KNOWN, SPRING RATE IS SLOPE OF CURVE AT THAT LATERAL LOAD.
IF LATERAL LOAD IS VARIABLE, ASSUME STRAIGHT LINE BETWEEN 0 AND MAX ESTIMATED LATERAL LOAD.
1750 LBS
22 PSI
2200 LBS
25 PSI
1.75
1.50
1.25
1.0
.75
.50
.25
0
100
200
300
400
500
600
700
800
900
1000


MD-319527
30X12.50-16.5 WRANGLER RT II
RIM 8.25
300165-6-TTR-10
LAB DATA 3-17-84
20 PSI
25 PSI
30 PSI
3.6
3.2
2.8
2.4
2.0
1.6
DEFLECTION IN INCHES
36
32
28
24
20
PERCENT DEFLECTION
14.8
15.2
15.6
16.0
16.4
RADIUS IN INCHES



STATIC LOADED
18.0
17.2
17.6
18.0
18.4
12
8
4
0
CA
MB
CL
CM
12.8
13.0
13.2
13.4
LOADED OVERALL
20
40
60
80
CONTACT AREA IN SQUAR
0
1
2
3
4
5
6
LOAD IN THOUSANDS OF POUNDS

C-8



TOLERANCE ON FINISHED SURFACES ±.010" ON FRACTIONAL DIMENSIONS

THE SUBJECT MATTER OF THIS DRAWING IS THE PROPERTY OF THE GOODYEAR TIRE AND RUBBER COMPANY OF AKRON, OHIO

MD-319527

HE GOODYEAR TIRE & RUBBER COMPANY, AKRON, OHIO

TLE 36X12 50-18 S HRL RT 11

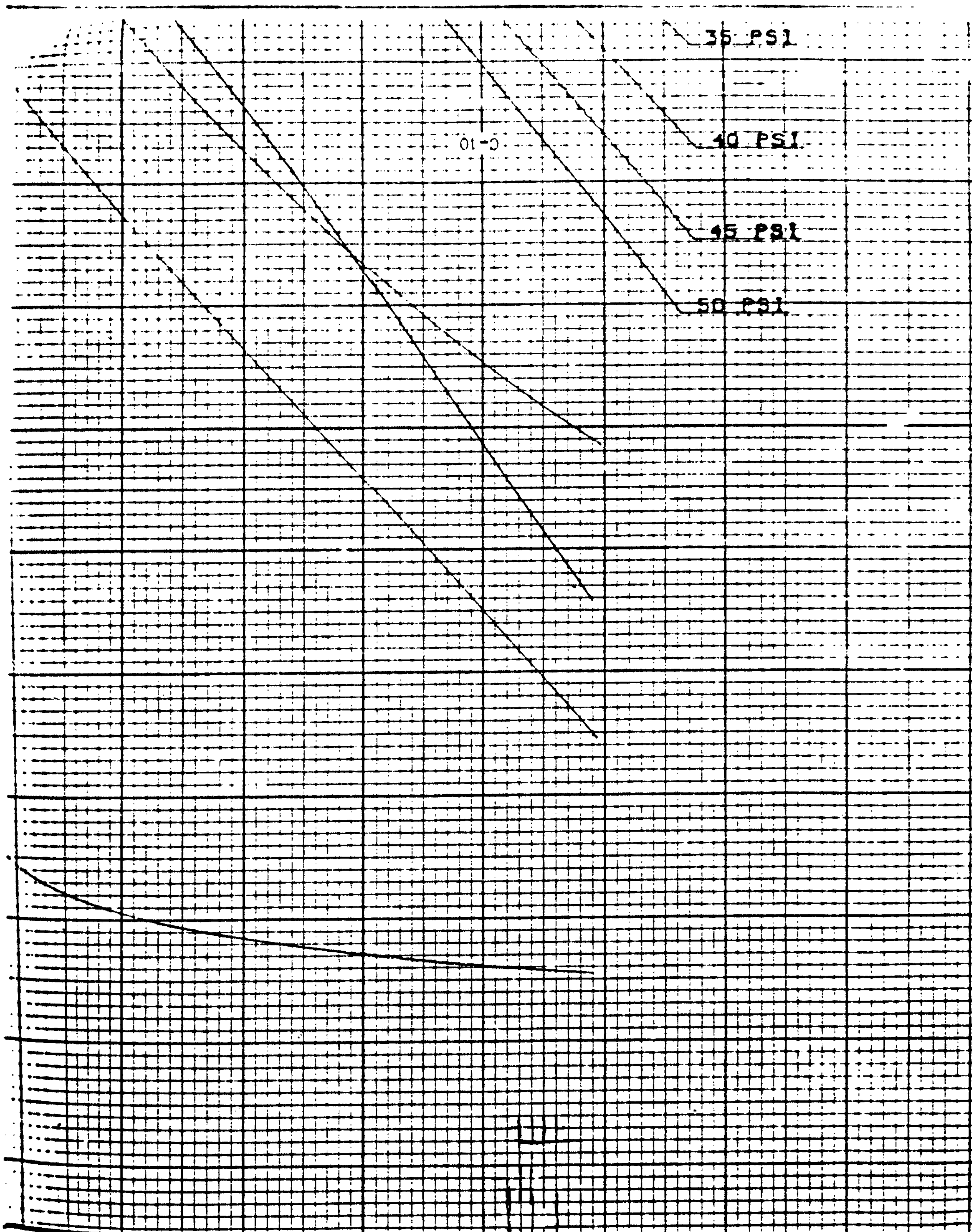
EFLECTION CURVES

SCALE

DEPT. 460B

DRAWN BY ORTHO JUN 4-18-84 CHKD. BY

TRACED BY 19 APPRD BY



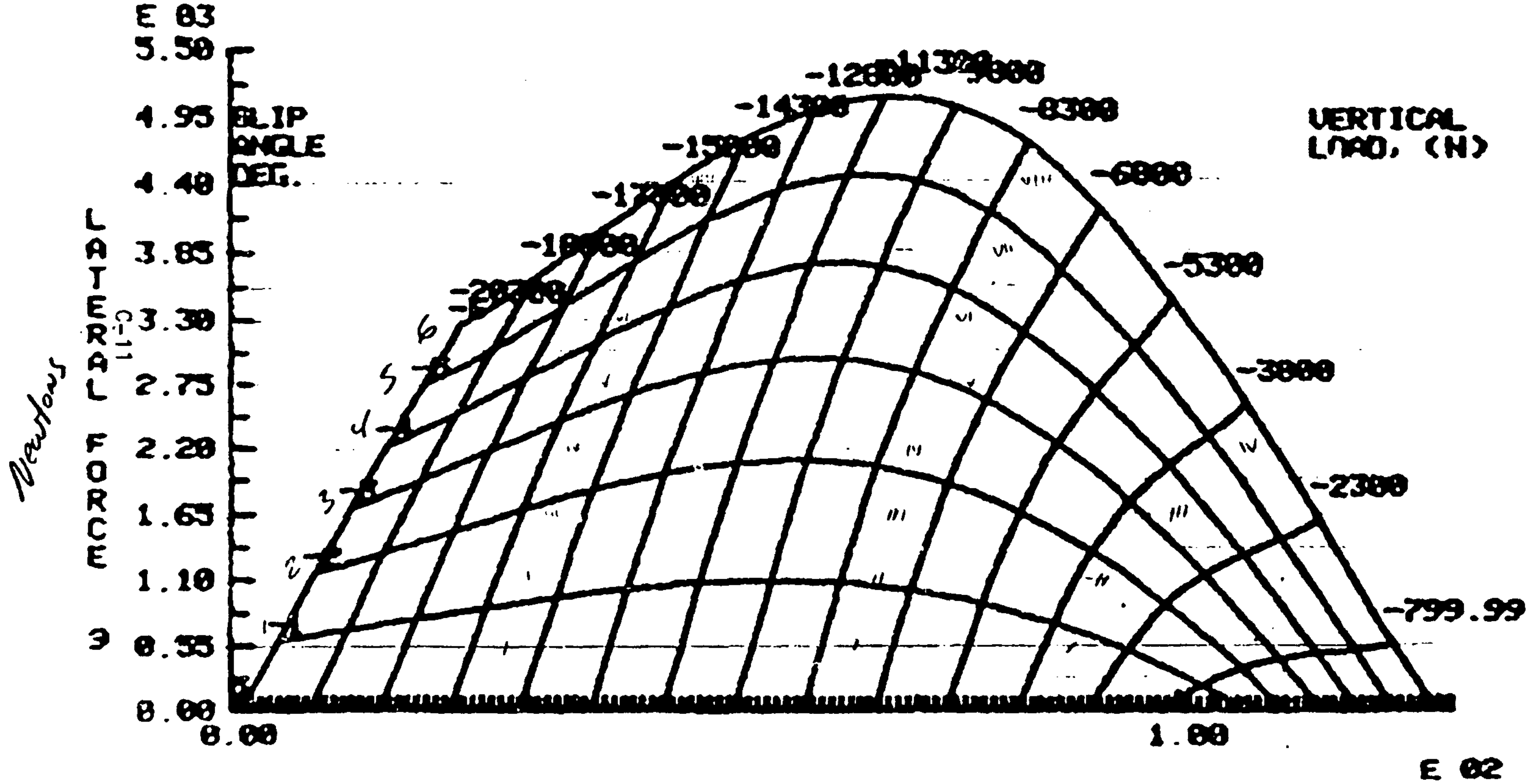
1 REV. BY ____ 19__	2 REV. BY ____ 19__	3 REV. BY ____ 19__

JOB 0-5585

36x12.50-16.5LT WRA: ?LER R/T II - Bias Type
20 PSI

LATERAL FORCE VS SLIP ANGLE AND VERTICAL LOAD

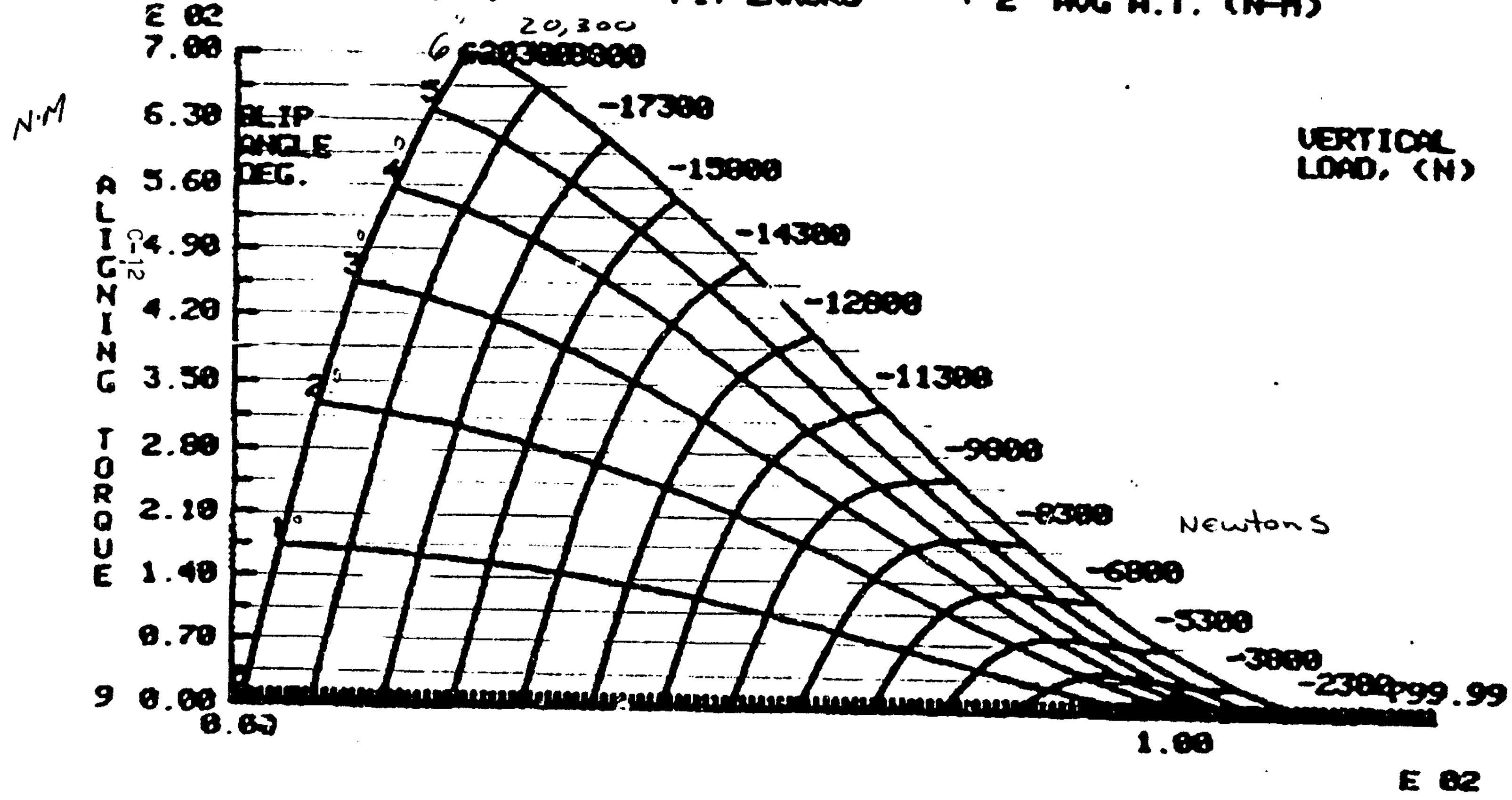
TEST DATA FILE#	T9099	TEST DATE/TIME	25-FEB-84/08:30
TIRE SIZE	36X12.5-16.5LT	MANUFACTURER	GTR
INFLATION (KPA)	138	RIM WIDTH (IN)	8.25
CONSTR.-DASH	3C0165-7	AMB TEMP (C)	26.2
TEST NUMBER	3C016T-L16A	TIRE TYPE	WRANGLER R/T II
MAX SLIP ANGLE	6	ORIGINATR(INIT)	LAWRENCE (REB)
TEST LOAD (N)	12675	FIT ERRORS	42.82 AVG L.F. (N)



36x12.50-16.5LT WRANGLER R/T II - Bias Type
20 psi

ALIGNING TORQUE VS SLIP ANGLE AND VERTICAL LOAD

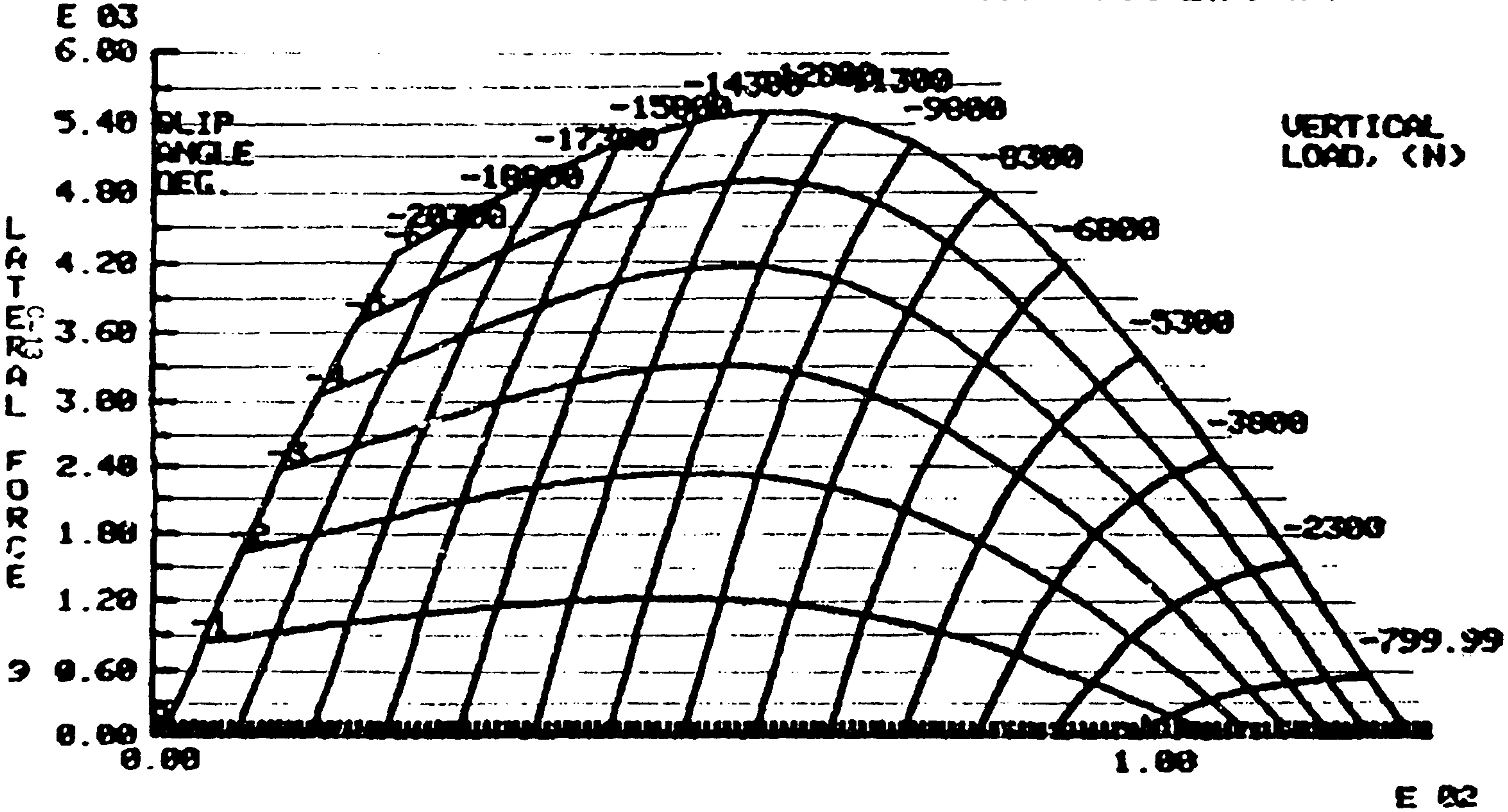
TEST DATA FILE#	T9099	TEST DATE/TIME	25-FEB-84/08:38
TIRE SIZE	36X12.5-16.5LT	MANUFACTURER	GTR
INFLATION (KPA)	138	RIM WIDTH (IN)	8.25
CONSTR.-DASH	3C8165-7	AMB TEMP (C)	26.2
TEST NUMBER	3C816T-L16A	TIRE TYPE	WRANGLER R/T II
MAX SLIP ANGLE	6	ORIGINATR(INIT)	LAWRENCE (REB)
TEST LOAD (N)	12675	FIT ERRORS	2 AVG A.T. (N-M)



36 x 12.50 - 16.5LT WRAN LER R/T II - Bias Type
22 PSI

LATERAL FORCE VS SLIP ANGLE AND VERTICAL LOAD

TEST DATA FILE#	T9098	TEST DATE/TIME	24-FEB-84/23:17
TIRE SIZE	36X12.50-16.5L	MANUFACTURER	GDYR
INFLATION (KPA)	152	RIM WIDTH (IN)	8.25
CONSTR.-DASH	3C0165-7	AMB TEMP (C)	25.8
TEST NUMBER	3C016T-L16A	TIRE TYPE	WRANGLER R/T 2
MAX SLIP ANGLE	6	ORIGINATR(INIT)	LAWRENCE (CH)
TEST LOAD (N)	12675	FIT ERRORS	30.24 AVG L.F. (N)

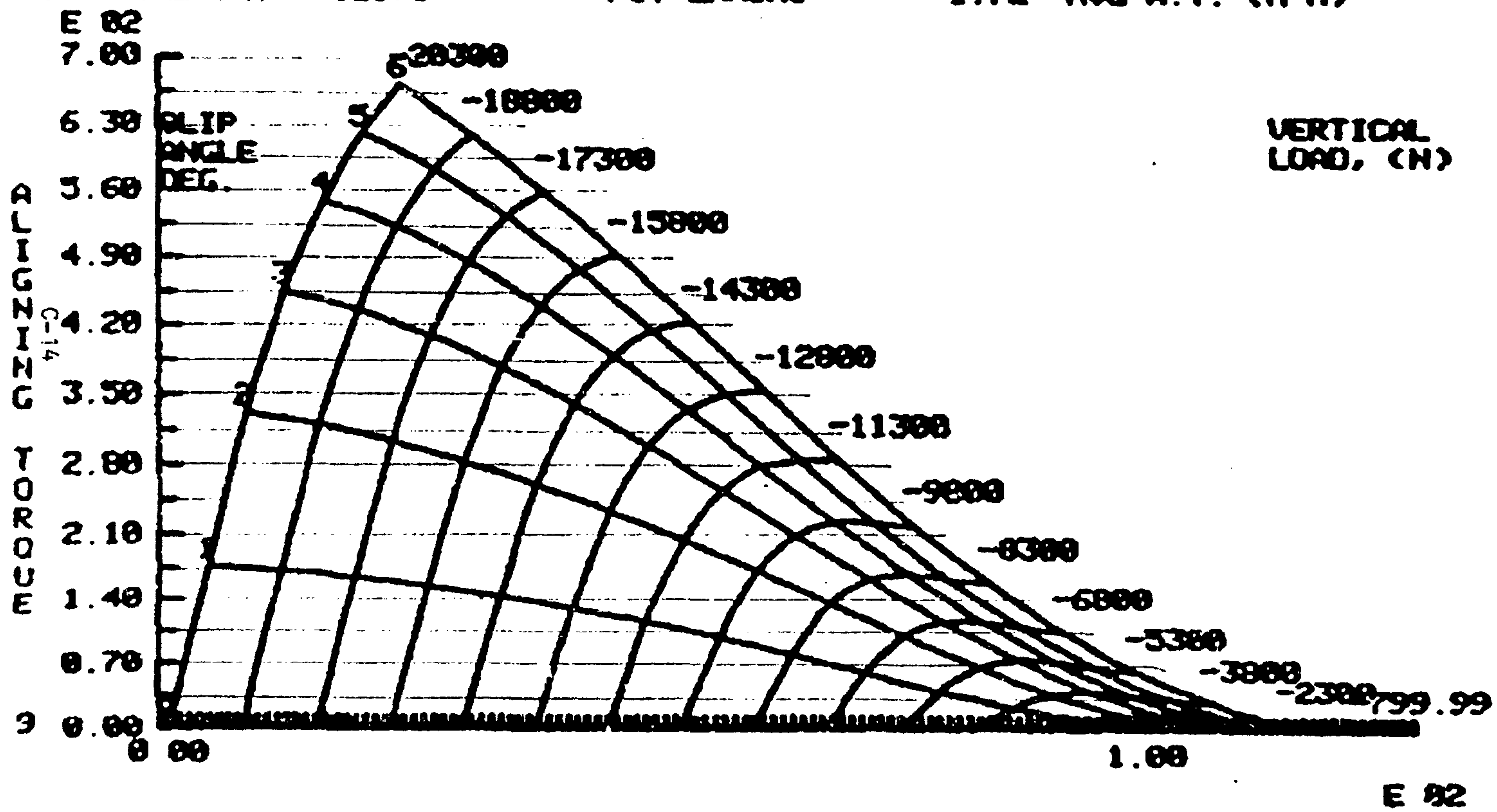


36 X 12.50-16.5LT WR VGLER R/T II Bias Type

22 PSI

ALIGNING TORQUE VS SLIP ANGLE AND VERTICAL LOAD

TEST DATA FILE#	:T9098	TEST DATE/TIME	:24-FEB-84/23:17
TIRE SIZE	:36X12.50-16.5L	MANUFACTURER	:GDYR
INFLATION (KPA)	:152	RIM WIDTH (IN)	:8.25
CONSTR.-DASH	:3C0165-7	AMB TEMP (C)	:25.8
TEST NUMBER	:3C016T-L16A	TIRE TYPE	:WRANGLER R/T 2
MAX SLIP ANGLE	:6	ORIGINATR(INIT)	:LAWRENCE (CH)
TEST LOAD (N)	:12675	FIT ERRORS	: 1.72 AVG A.T. (N-M)

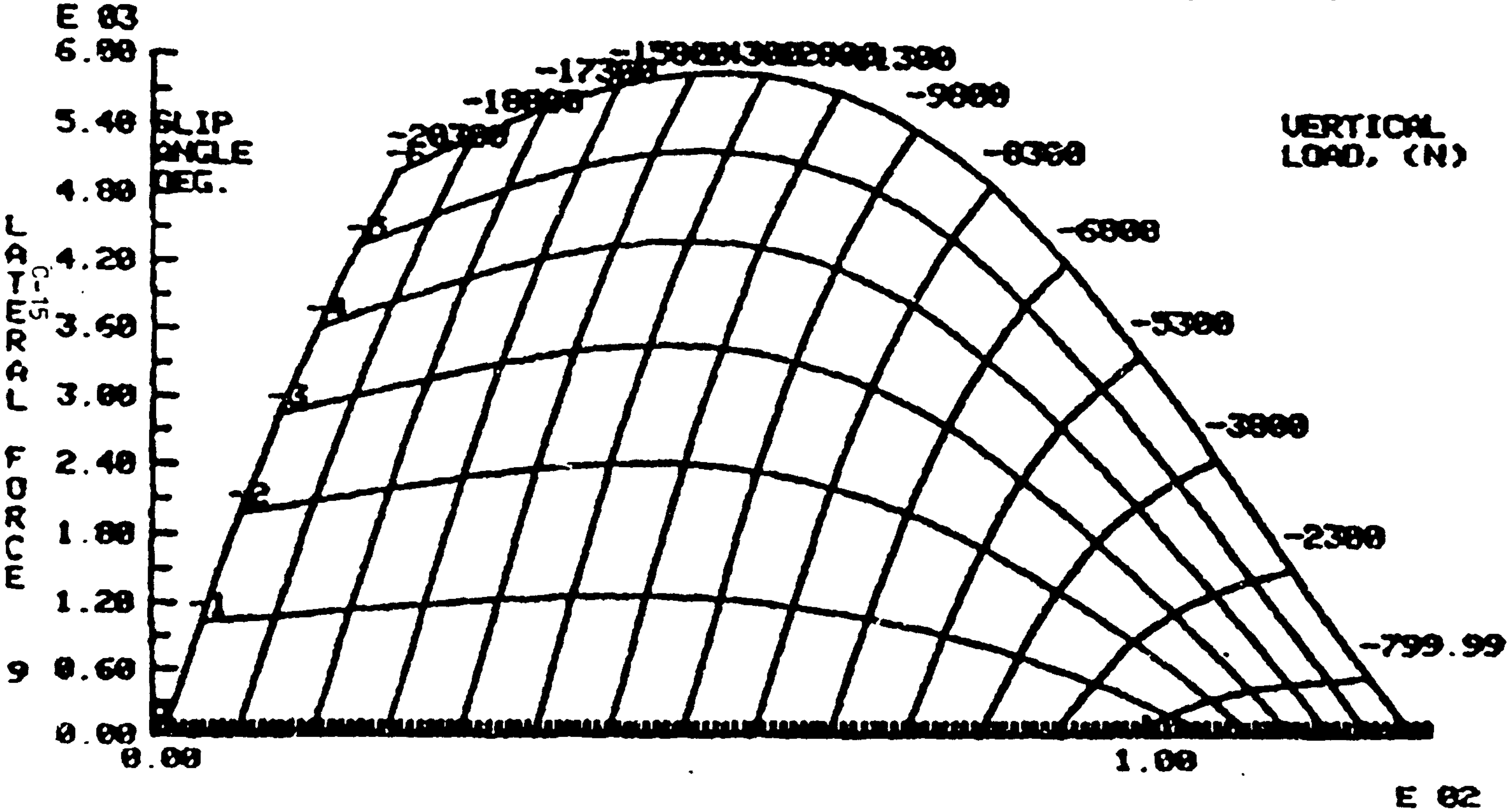


C-14

36X12.50-16.5LT WRANGLER R/T II - Bias Type
25 PSI

LATERAL FORCE VS SLIP ANGLE AND VERTICAL LOAD

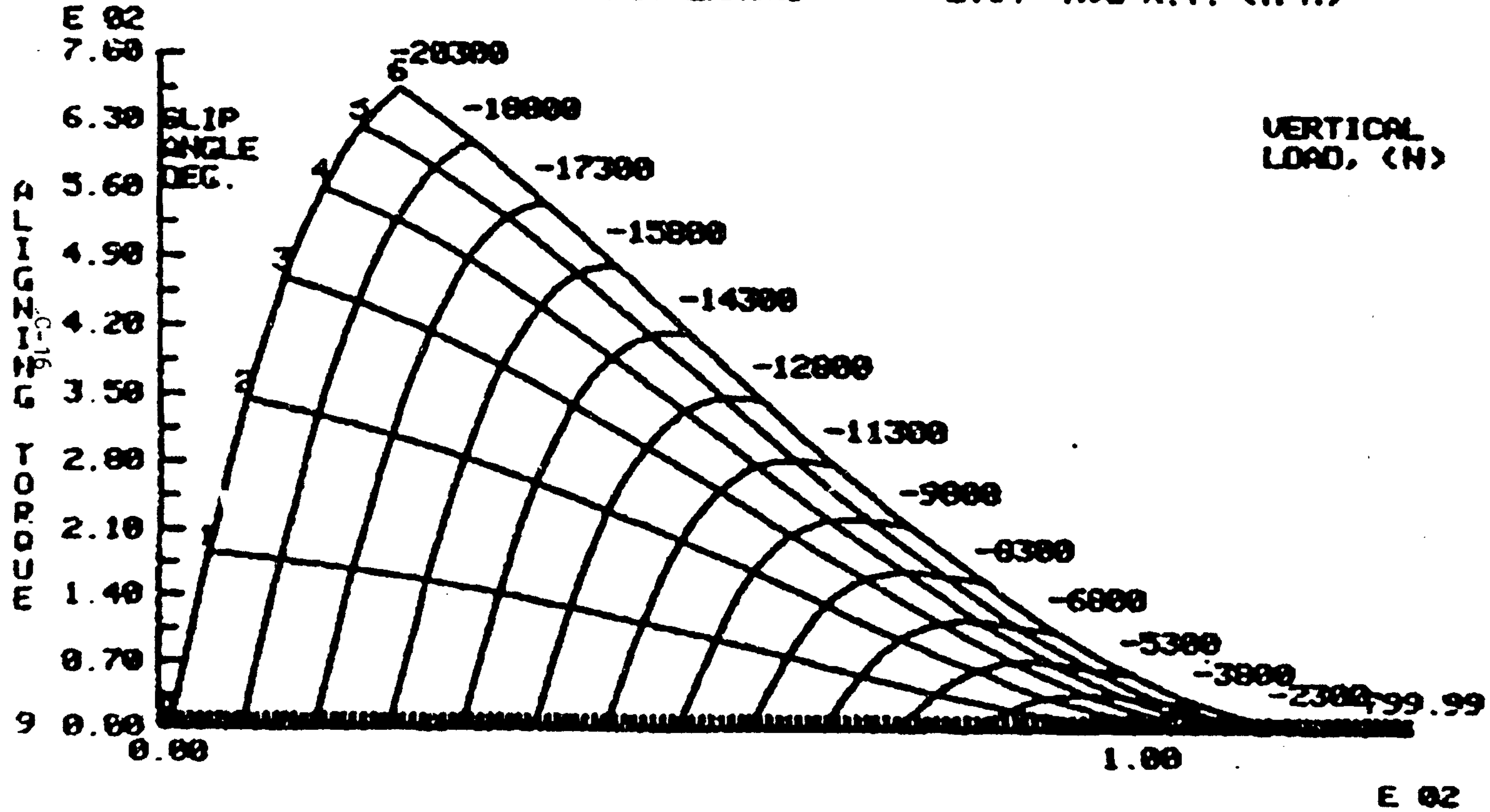
TEST DATA FILE#	:T9096	TEST DATE/TIME	:24-FEB-84/20:57
TIRE SIZE	:36X12.50-16.5	MANUFACTURER	:GDYR
INFLATION (KPA)	:172	RIM WIDTH (IN)	:8.25
CONSTR.-DASH	:3C0165-4	AMB TEMP (C)	:23.5
TEST NUMBER	:3C016T-L168	TIRE TYPE	:WRANGLER R/T 2
MAX SLIP ANGLE	:6	ORIGINATR(INIT)	:LAWRENCE (CH)
TEST LOAD (N)	:12675	FIT ERRORS	: 26.38 AVG L.F. (N)



36 x 12.50 - 16.5 LT WRAN -ER R/T II - Bias Type
25 psi

ALIGNING TORQUE VS SLIP ANGLE AND VERTICAL LOAD

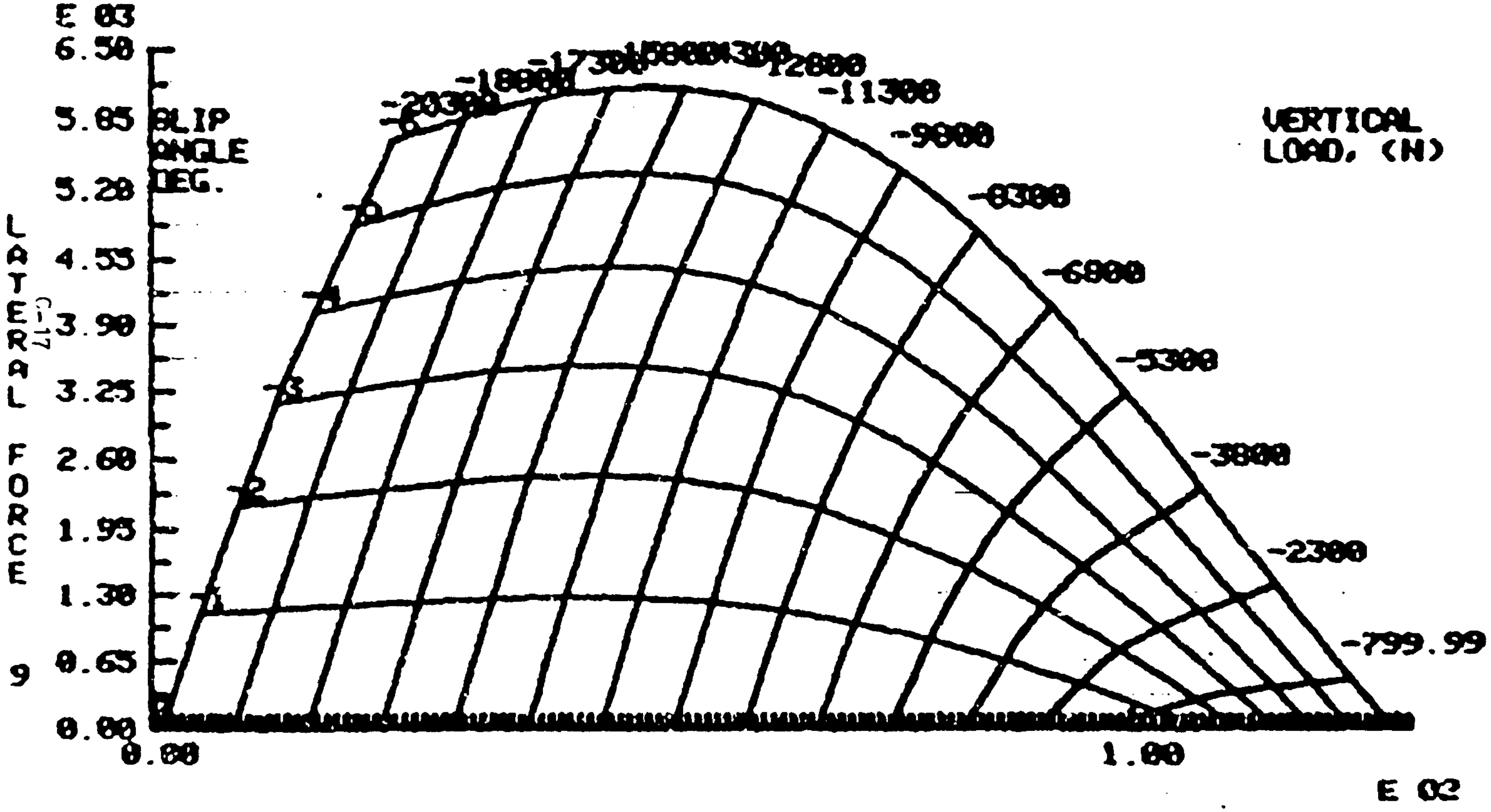
TEST DATA FILE#	:T9096	TEST DATE/TIME	:24-FEB-84/20:57
TIRE SIZE	:36X12.50-16.5	MANUFACTURER	:GDYR
INFLATION (KPA)	:172	RIM WIDTH (IN)	:8.25
CONSTR.-DASH	:3C0165-4	AMB TEMP (C)	:23.5
TEST NUMBER	:3C016T-L168	TIRE TYPE	:WRANGLER R/T 2
MAX SLIP ANGLE	:6	ORIGINATR(INIT)	:LAWRENCE (CH)
TEST LOAD (N)	:12675	FIT ERRORS	: 2.14 AVG A.T. (N-M)



36 X 12.50 - 16.5 LT WRANGLER R/T II - Bias Type
28 PSI

LATERAL FORCE VS SLIP ANGLE AND VERTICAL LOAD

TEST DATA FILE#	T9097	TEST DATE/TIME	24-FEB-84/22:12
TIRE SIZE	36X12.50-16.5	MANUFACTURER	GDYR
INFLATION (KPA)	193	RIM WIDTH (IN)	8.25
CONSTR.-DASH	3C0163-4	AMB TEMP (C)	24.4
TEST NUMBER	3C016T-L168	TIRE TYPE	WRANGLRE R/T 2
MAX SLIP ANGLE	6	ORIGINATR(INIT)	LAWRENCE (CH)
TEST LOAD (N)	12675	FIT ERRORS	15.51 AVG L.F. (N)



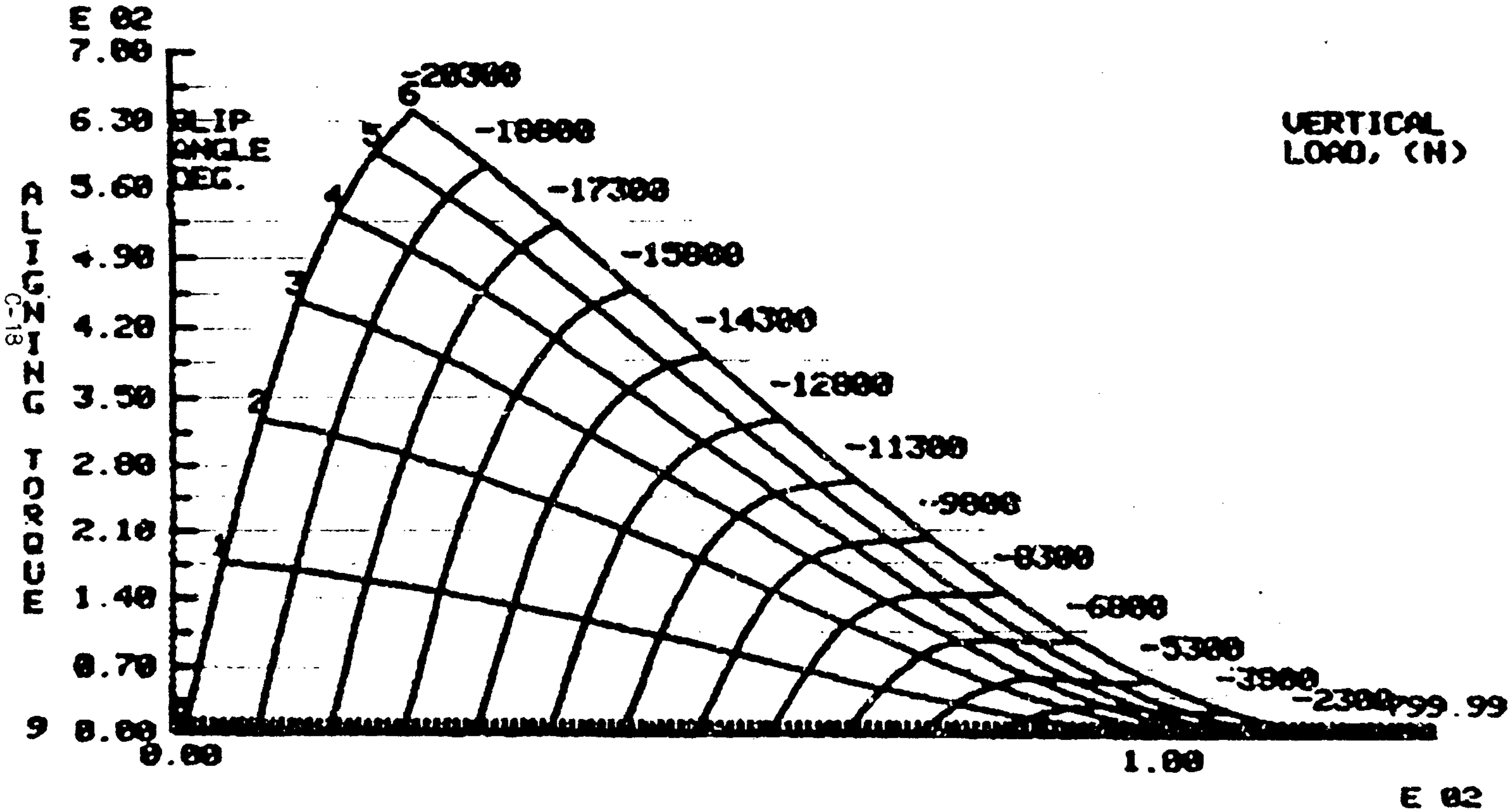
C-17

36 x 12.50 - 16.5 LT WRANGLER R/T II - Bias Type

28 psi

ALIGNING TORQUE VS SLIP ANGLE AND VERTICAL LOAD

TEST DATA FILE#	T9097	TEST DATE/TIME	24-FEB-84/22:12
TIRE SIZE	36X12.50-16.5	MANUFACTURER	GDYR
INFLATION (KPA)	193	RIM WIDTH (IN)	8.25
CONSTR.-DASH	3C0163-4	AMB TEMP (C)	24.4
TEST NUMBER	3C016T-L168	TIRE TYPE	WRANGLRE R/T 2
MAX SLIP ANGLE	6	ORIGINATR(INIT)	LAWRENCE (CH)
TEST LOAD (N)	12675	FIT ERRORS	1.74 AVG A.T. (N-M)



APPENDIX D

NATC TERRAIN DATA

Course Profile
17-297

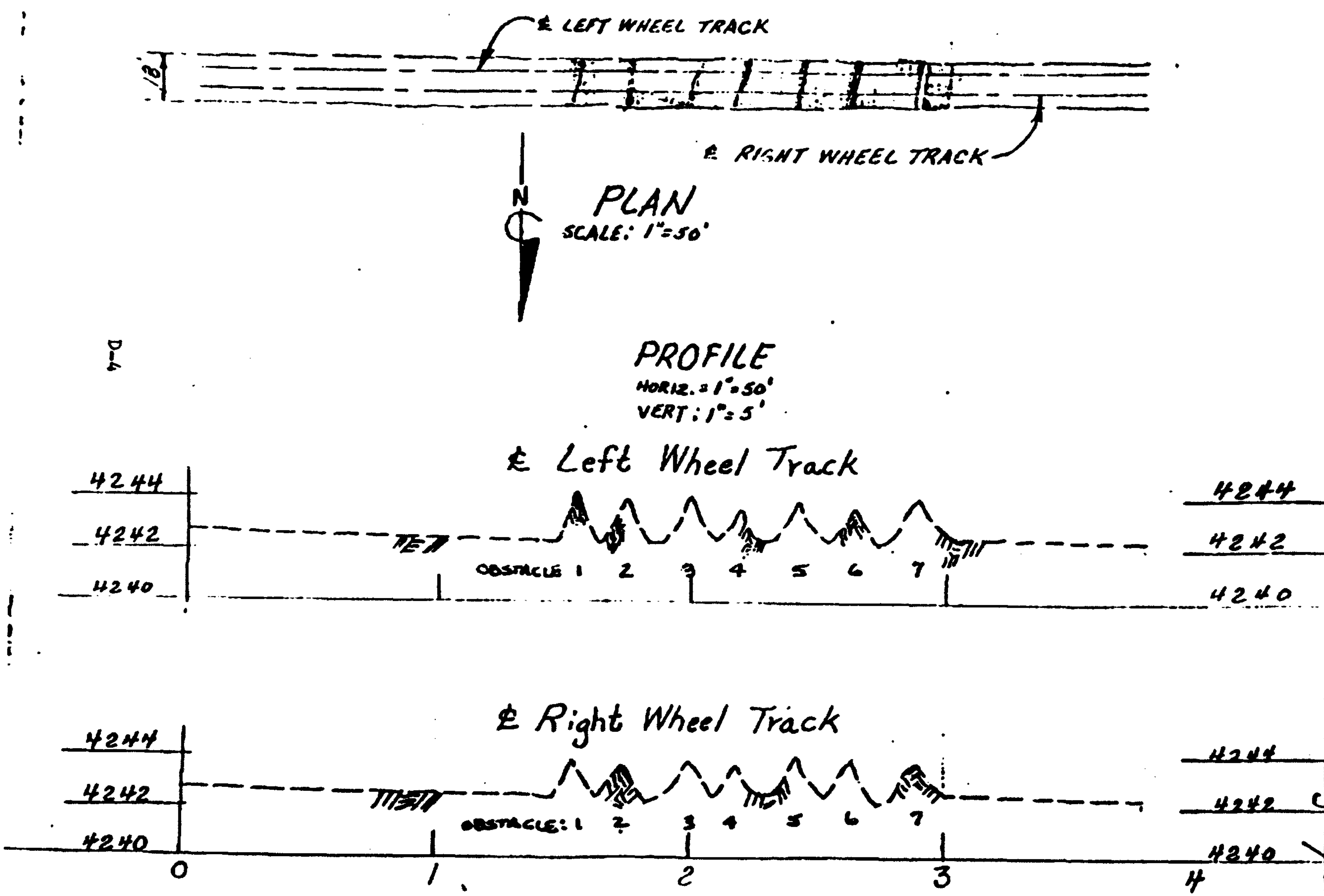
5-26-87
Cloudy Windy
553
$\bar{\Lambda}$ Lockhart
ϕ Cornell

$\bar{\Lambda}$ @ Sta. 0+00 H.I. = 5.12'
El. = 4242.67
B.S. Cp4 El. = 4242.86
found 1"x2" Hub
V∢ = 90°-19'-40" = -00°-19'-40"
Slope Dist. = 103.44'
Horiz Dist. = 103.44'
Vert. Dist. = -0.59'

F.S.

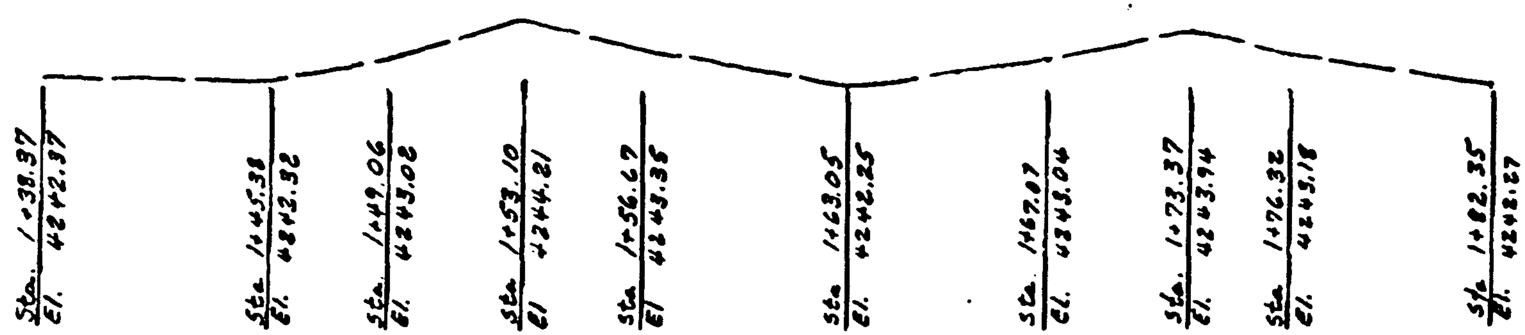
Left Wheel Track		Right Wheel Track		Left cont.		Right cont.	
Station	Elevation	Station	Elevation	Station	Elevation	Station	Elevation
1+38.37	4242.37	1+39.58	4242.46	2+18.90	4243.50	2+19.92	4243.60
1+45.28	4242.32	1+45.38	4242.32	2+23.89	4242.52	2+23.64	4242.80
1+49.06	4243.02	1+49.45	4243.02	2+28.51	4242.30	2+28.54	4242.39
1+53.10	4244.21	1+52.94	4243.79	2+33.23	4242.44	2+32.77	4242.48
1+56.67	4243.35	1+56.69	4243.19	2+38.72	4243.22	2+38.50	4243.18
1+63.05	4242.25	1+62.80	4242.36	2+41.75	4243.87	2+41.45	4243.94
1+69.07	4243.04	1+69.40	4243.21	2+45.51	4243.03	2+44.76	4243.17
1+73.37	4242.94	1+73.21	4243.57	2+53.71	4242.32	2+53.24	4242.35
1+76.32	4243.19	1+76.48	4243.02	2+60.26	4243.05	2+60.07	4243.33
1+82.35	4242.27	1+82.00	4242.16	2+63.43	4243.55	2+63.10	4243.83
1+87.75	4242.31	1+88.22	4242.45	2+67.03	4242.96	2+67.05	4243.04
1+94.65	4243.08	1+94.62	4242.94	2+73.52	4242.18	2+73.81	4242.10
1+99.41	4244.07	1+99.21	4243.75	2+79.42	4242.59	2+79.22	4242.32
2+03.25	4243.10	2+03.28	4243.30	2+85.07	4243.50	2+85.67	4243.37
2+09.76	4242.36	2+09.56	4242.38	2+88.82	4243.95	2+89.88	4243.76
2+15.66	4242.89	2+16.01	4243.12	2+93.74	4243.26	2+94.15	4243.06
				3+00.97	4242.58	3+00.61	4242.46

3+78.68 4242.32


℄ LEFT WHEEL TRACK
18'
℄ RIGHT WHEEL TRACK
N
PLAN
SCALE: 1"=50'
PROFILE
HORIZ.: 1"=50'
VERT: 1"=5'
℄ Left Wheel Track
4244
4242
4240
OBSTACLE 1 2 3 4 5 6 7
℄ Right Wheel Track
OBSTACLE: 1 2 3 4 5 6 7
0
1
2
3
4

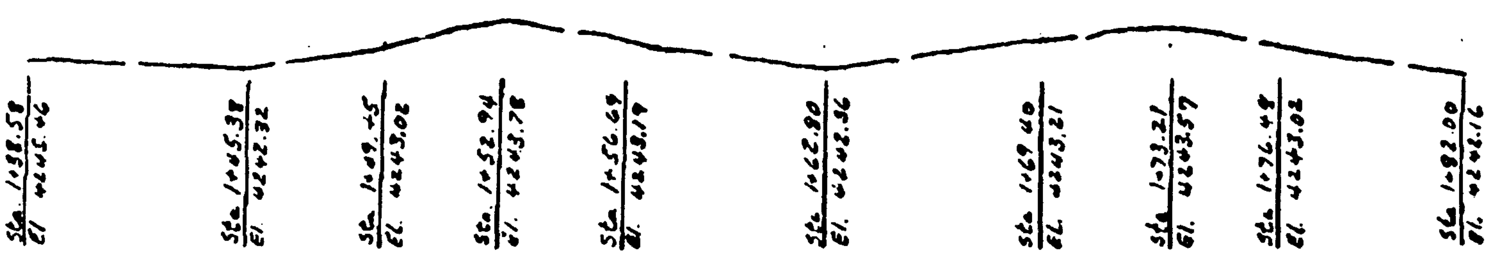
LEFT WHEEL TRACK

OBSTACLE: 1 2



RIGHT WHEEL TRACK

OBSTACLE: 1 2



Horiz. Scale: 1"=5'
Vert. Scale: 1"=5'

APPENDIX E

DYNAMIC ANALYSIS VEHICLE INPUT DATA FILES

FILE: [AARDEMA.DADS3D.HMMWV.1037.HIGHCG.NATC]HMMWV_15MPH.VB3

CREATE HEADER

*

1. This a model of the high C.G. HMMWV M1037 S-250 Shelter Carrier vehicle with bias tires.

*

2. This model was used to determine the forces within the spherical joints.

*

3. The spherical joint axis on the wheel are arranged such that the Z axis is along the King-Pin axis. If the forces are reported in the joint coordinate system, then the forces acting on the wheel along the joint Z axis would represent the tensile force in the spherical joint. Likewise th forces acting on the wheel along the joint X and Y axis are the shear forces in the spherical joint.

*

4. The spherical joint axis on the arms are arranged to represent the mountin surface upon which the spherical joint is bolted.

*

5. By taking the dot product of the two joint Z axis, the angular displacemen of the spherical joint can be calculated. This was done in the subroutine FRC15.FOR.

*

6. See the user written subroutine USER_TSDA.FOR for the shock model. The subroutine will provide additional comments in more detail.

*

7. A user written tire element data was written to calculate the tire forces. This was implemented in module 36 and is call TACOM-TIRE. See the source code for additional comments and methods used in implementing user force elements. The TACOM-TIRE module input data was design to be used with the preproccessor's tire data and supplementted with the data in the user input file. The user input file has a .INP extension. See the subroutines FRC36.FOR, TIREF.FOR, and USET.FOR for more detailed information.

*

8. *************** IMPORTANT NOTE - PLEASE READ ****************************
******************   ****************************

If the preproccessor is used to create the tire force element, then the element name in the .FM3 file must be changed from TIRE to TACOM-TIRE. This will then instruct the dads code to call the TACOM-TIRE model located in module number 36. If the name of the element name is not changed and remains TIRE, then the original CADSI tire model will be called. When changing the name, be careful to keep the orignal record format.

*

9. The print interval is set to 1/60 second. This will allow greater accurac when finding the maximum forces. If a larger time step was used the maximum force in a spike could be attenuated leading to a misrepresentation of the results. The animation can skip a frame and still maintain a 1/30 second time step per frame.

*

10. The front tires are bias type at 20 psi
The rear tires are bias type at 30 psi
Vertical force versus deflection curves for all tire are taken from the Goodyear Data. The lateral force versus slip angle curves was taken from the UMTRI data because the UMTRI data is valid upto 16 degrees of slip.

*

11. Assume the center of gravity of each wheel is at the wheel center. The angle of 0.247 degrees associated with each wheel represents the toe-in of the front wheels and the toe-out of the rear wheels. See the HMMWV Technical Manual TM 9-2320-280-20, sections 8-6 and 8-7.
*

```
ANALYSIS
CREATE SYSTEM.DATA
    UNITS                                   := 'ENG'
    ANALYSIS.TYPE                           := 'DYNAMIC'
    STARTING.TIME                           := '0.0'
    ENDING.TIME                             := '12.0'
    PRINT.INTERVAL                          := '0.0166666666666666'
    GRAVITY.SEA.LEVEL                       := '386.400'
    X.GRAVITY                               := '0.0'
    Y.GRAVITY                               := '0.0'
    Z.GRAVITY                               := '-1.0'
    SCALE.GRAVITY.COEF                      := '1.0'
    MATRIX.OPERATIONS                       := 'SPARSE'
    REDUNDANCY.CHECK                        := 'TRUE'
    LU.TOL                                  := '1.0D-12'
    ASSEMBLY.TOL                            := '1.0D-3'
    BYPASS.ASSEMBLY                         := 'FALSE'
    OUTPUT.FILE                             := 'BINARY'
    REFERENCE.FRAME                         := 'GLOBAL'
    DEBUG.FLAG                              := 'TRUE'
UP
CREATE DYNAMIC.DATA
    REACTION.FORCES                         := 'TRUE'
    FORCE.COORDINATES                       := 'JOINT'
    PRINT.METHOD                            := 'INTERPOLATED'
    MAX.INT.STEP                            := '0.05'
    SOLUTION.TOL                            := '0.001'
    INTEGRATION.TOL                         := '0.0001'
UP
UP
CONSTRAINTS
CREATE DISTANCE.CONSTRAINT
    NAME                                    := 'TIE-ROD.FL'
    BODY.1.NAME                             := 'STEERING.LINK'
    BODY.2.NAME                             := 'WHEEL.FL'
    P.ON.BODY.1                             := ( -17.655, -47.635, 32.905 )
    P.ON.BODY.2                             := ( -32.327, -44.702, 30.127 )
    Q.ON.BODY.1                             := ( -17.655, -47.635, 33.905 )
    Q.ON.BODY.2                             := ( -32.327, -44.702, 31.127 )
    R.ON.BODY.1                             := ( -16.655, -47.635, 32.905 )
    R.ON.BODY.2                             := ( -31.327, -44.702, 30.127 )
    DISTANCE                                := '15.217994513076'
    NODE.1                                  := '0'
    NODE.2                                  := '0'
UP
CREATE DISTANCE.CONSTRAINT
    NAME                                    := 'TIE-ROD.FR'
    BODY.1.NAME                             := 'STEERING.LINK'
```

```
      BODY.2.NAME                            := 'WHEEL.FR'
      P.ON.BODY.1                            := ( 17.655, -47.635, 32.905 )
      P.ON.BODY.2                            := ( 32.327, -44.702, 30.127 )
      Q.ON.BODY.1                            := ( 17.655, -47.635, 33.905 )
      Q.ON.BODY.2                            := ( 32.327, -44.702, 31.127 )
      R.ON.BODY.1                            := ( 18.655, -47.635, 32.905 )
      R.ON.BODY.2                            := ( 33.327, -44.702, 30.127 )
      DISTANCE                               := '15.217994513076'
      NODE.1                                 := '0'
      NODE.2                                 := '0'
   UP
   CREATE DISTANCE.CONSTRAINT
      NAME                                   := 'RAD-ROD.RL'
      BODY.1.NAME                            := 'CHASSIS'
      BODY.2.NAME                            := 'WHEEL.RL'
      P.ON.BODY.1                            := ( -16.380, -161.980, 33.080 )
      P.ON.BODY.2                            := ( -32.327, -164.066, 30.405 )
      Q.ON.BODY.1                            := ( -16.380, -161.980, 34.080 )
      Q.ON.BODY.2                            := ( -32.327, -164.066, 31.405 )
      R.ON.BODY.1                            := ( -15.380, -161.980, 33.080 )
      R.ON.BODY.2                            := ( -31.327, -164.066, 30.405 )
      DISTANCE                               := '16.303798023773'
      NODE.1                                 := '0'
      NODE.2                                 := '0'
   UP
   CREATE DISTANCE.CONSTRAINT
      NAME                                   := 'RAD-ROD.RR'
      BODY.1.NAME                            := 'CHASSIS'
      BODY.2.NAME                            := 'WHEEL.RR'
      P.ON.BODY.1                            := ( 16.380, -161.980, 33.080 )
      P.ON.BODY.2                            := ( 32.327, -164.066, 30.405 )
      Q.ON.BODY.1                            := ( 16.380, -161.980, 34.080 )
      Q.ON.BODY.2                            := ( 32.327, -164.066, 31.405 )
      R.ON.BODY.1                            := ( 17.380, -161.980, 33.080 )
      R.ON.BODY.2                            := ( 33.327, -164.066, 30.405 )
      DISTANCE                               := '16.303798023773'
      NODE.1                                 := '0'
      NODE.2                                 := '0'
   UP
   UP
   FORCE
   CREATE TIRE
      NAME                                   := 'TIRE.FL'
      TIRE.BODY                              := 'WHEEL.FL'
      CHASSIS.BODY                           := 'CHASSIS'
      TYPE                                   := 'BASIC'
      P.ON.TIRE                              := ( -35.815, -39.370, 29.735 )
      RADIUS                                 := '18.150'
      ROLLING.RESISTANCE                     := '0.0'
      DAMPING.CONSTANT                       := '100.000'
      VERTICAL.STIFF                         := '0.0'
      LATERAL.STIFF                          := '0.0'
      STEER.ANGLE                            := '0.0'
      FRICTION.COEFF                         := '0.7'
```

```
      CURVE.UTILITY                        := 'TIRE.COEF'
      CURVE.VERTICAL                       := 'BIAS.TIRE.20PSI'
      CURVE.TORQUE                         := 'NONE'
      CURVE.STEER                          := 'TRAJECTORY'
      ANGULAR.UNITS                        := 'DEGREES'
   UP
   CREATE TIRE
      NAME                                 := 'TIRE.FR'
      TIRE.BODY                            := 'WHEEL.FR'
      CHASSIS.BODY                         := 'CHASSIS'
      TYPE                                 := 'BASIC'
      P.ON.TIRE                            := ( 35.815, -39.370, 29.735 )
      RADIUS                               := '18.150'
      ROLLING.RESISTANCE                   := '0.0'
      DAMPING.CONSTANT                     := '100.000'
      VERTICAL.STIFF                       := '0.0'
      LATERAL.STIFF                        := '0.0'
      STEER.ANGLE                          := '0.0'
      FRICTION.COEFF                       := '0.7'
      CURVE.UTILITY                        := 'TIRE.COEF'
      CURVE.VERTICAL                       := 'BIAS.TIRE.20PSI'
      CURVE.TORQUE                         := 'NONE'
      CURVE.STEER                          := 'NONE'
      ANGULAR.UNITS                        := 'DEGREES'
   UP
   CREATE TIRE
      NAME                                 := 'TIRE.RL'
      TIRE.BODY                            := 'WHEEL.RL'
      CHASSIS.BODY                         := 'CHASSIS'
      TYPE                                 := 'BASIC'
      P.ON.TIRE                            := ( -35.815, -169.370, 29.735 )
      RADIUS                               := '18.150'
      ROLLING.RESISTANCE                   := '0.0'
      DAMPING.CONSTANT                     := '100.000'
      VERTICAL.STIFF                       := '0.0'
      LATERAL.STIFF                        := '0.0'
      STEER.ANGLE                          := '0.0'
      FRICTION.COEFF                       := '0.7'
      CURVE.UTILITY                        := 'TIRE.COEF'
      CURVE.VERTICAL                       := 'BIAS.TIRE.30PSI'
      CURVE.TORQUE                         := 'NONE'
      CURVE.STEER                          := 'NONE'
      ANGULAR.UNITS                        := 'DEGREES'
   UP
   CREATE TIRE
      NAME                                 := 'TIRE.RR'
      TIRE.BODY                            := 'WHEEL.RR'
      CHASSIS.BODY                         := 'CHASSIS'
      TYPE                                 := 'BASIC'
      P.ON.TIRE                            := ( 35.815, -169.370, 29.735 )
      RADIUS                               := '18.150'
      ROLLING.RESISTANCE                   := '0.0'
      DAMPING.CONSTANT                     := '100.000'
      VERTICAL.STIFF                       := '0.0'
```

```
    LATERAL.STIFF                         := '0.0'
    STEER.ANGLE                           := '0.0'
    FRICTION.COEFF                        := '0.7'
    CURVE.UTILITY                         := 'TIRE.COEF'
    CURVE.VERTICAL                        := 'BIAS.TIRE.30PSI'
    CURVE.TORQUE                          := 'NONE'
    CURVE.STEER                           := 'NONE'
    ANGULAR.UNITS                         := 'DEGREES'
UP
CREATE TSDA
    NAME                                  := 'SPRING.FL'
    BODY.1.NAME                           := 'CHASSIS'
    BODY.2.NAME                           := 'ARM.LFL'
    SPRING.CONSTANT                       := '954.000'
    FREE.LENGTH.SPRING                    := '13.360'
    DAMPING.COEFFICIENT                   := '0.0'
    ACTUATOR.FORCE                        := '0.0'
    P.ON.BODY.1                           := ( -20.070, -33.685, 38.545 )
    P.ON.BODY.2                           := ( -21.385, -33.953, 28.935 )
    Q.ON.BODY.1                           := ( -20.070, -33.685, 39.545 )
    Q.ON.BODY.2                           := ( -21.385, -33.953, 29.935 )
    R.ON.BODY.1                           := ( -19.070, -33.685, 38.545 )
    R.ON.BODY.2                           := ( -20.385, -33.953, 28.935 )
    CURVE.SPRING                          := 'NONE'
    CURVE.DAMPER                          := 'NONE'
    CURVE.ACTUATOR                        := 'NONE'
    NODE.1                                := '0'
    NODE.2                                := '0'
UP
CREATE TSDA
    NAME                                  := 'SPRING.FR'
    BODY.1.NAME                           := 'CHASSIS'
    BODY.2.NAME                           := 'ARM.LFR'
    SPRING.CONSTANT                       := '954.000'
    FREE.LENGTH.SPRING                    := '13.360'
    DAMPING.COEFFICIENT                   := '0.0'
    ACTUATOR.FORCE                        := '0.0'
    P.ON.BODY.1                           := ( 20.070, -33.685, 38.545 )
    P.ON.BODY.2                           := ( 21.385, -33.953, 28.935 )
    Q.ON.BODY.1                           := ( 20.070, -33.685, 39.545 )
    Q.ON.BODY.2                           := ( 21.385, -33.953, 29.935 )
    R.ON.BODY.1                           := ( 21.070, -33.685, 38.545 )
    R.ON.BODY.2                           := ( 22.385, -33.953, 28.935 )
    CURVE.SPRING                          := 'NONE'
    CURVE.DAMPER                          := 'NONE'
    CURVE.ACTUATOR                        := 'NONE'
    NODE.1                                := '0'
    NODE.2                                := '0'
UP
CREATE TSDA
    NAME                                  := 'SPRING.RL'
    BODY.1.NAME                           := 'CHASSIS'
    BODY.2.NAME                           := 'ARM.LRL'
    SPRING.CONSTANT                       := '2108.000'
```

```
    FREE.LENGTH.SPRING                    := '15.030'
    DAMPING.COEFFICIENT                   := '0.0'
    ACTUATOR.FORCE                        := '0.0'
    P.ON.BODY.1                           := ( -19.747, -174.865, 40.868 )
    P.ON.BODY.2                           := ( -21.385, -174.597, 28.935 )
    Q.ON.BODY.1                           := ( -19.747, -174.865, 41.868 )
    Q.ON.BODY.2                           := ( -21.385, -174.597, 29.935 )
    R.ON.BODY.1                           := ( -18.747, -174.865, 40.868 )
    R.ON.BODY.2                           := ( -20.385, -174.597, 28.935 )
    CURVE.SPRING                          := 'NONE'
    CURVE.DAMPER                          := 'NONE'
    CURVE.ACTUATOR                        := 'NONE'
    NODE.1                                := '0'
    NODE.2                                := '0'
UP
CREATE TSDA
    NAME                                  := 'SPRING.RR'
    BODY.1.NAME                           := 'CHASSIS'
    BODY.2.NAME                           := 'ARM.LRR'
    SPRING.CONSTANT                       := '2108.00'
    FREE.LENGTH.SPRING                    := '15.030'
    DAMPING.COEFFICIENT                   := '0.0'
    ACTUATOR.FORCE                        := '0.0'
    P.ON.BODY.1                           := ( 19.747, -174.865, 40.868 )
    P.ON.BODY.2                           := ( 21.385, -174.597, 28.935 )
    Q.ON.BODY.1                           := ( 19.747, -174.865, 41.868 )
    Q.ON.BODY.2                           := ( 21.385, -174.597, 29.935 )
    R.ON.BODY.1                           := ( 20.747, -174.865, 40.868 )
    R.ON.BODY.2                           := ( 22.385, -174.597, 28.935 )
    CURVE.SPRING                          := 'NONE'
    CURVE.DAMPER                          := 'NONE'
    CURVE.ACTUATOR                        := 'NONE'
    NODE.1                                := '0'
    NODE.2                                := '0'
UP
CREATE TSDA
    NAME                                  := 'SHOCK.FL'
    BODY.1.NAME                           := 'CHASSIS'
    BODY.2.NAME                           := 'ARM.LFL'
    SPRING.CONSTANT                       := '0.0'
    FREE.LENGTH.SPRING                    := '0.0'
    DAMPING.COEFFICIENT                   := '0.0'
    ACTUATOR.FORCE                        := '0.0'
    P.ON.BODY.1                           := ( -19.598, -33.685, 43.492 )
    P.ON.BODY.2                           := ( -21.415, -33.953, 29.259 )
    Q.ON.BODY.1                           := ( -19.598, -33.685, 44.492 )
    Q.ON.BODY.2                           := ( -21.415, -33.953, 30.259 )
    R.ON.BODY.1                           := ( -18.598, -33.685, 43.492 )
    R.ON.BODY.2                           := ( -20.415, -33.953, 29.259 )
    CURVE.SPRING                          := 'NONE'
    CURVE.DAMPER                          := 'NONE'
    CURVE.ACTUATOR                        := 'NONE'
    NODE.1                                := '0'
    NODE.2                                := '0'
```

```
UP
CREATE TSDA
    NAME                          := 'SHOCK.FR'
    BODY.1.NAME                   := 'CHASSIS'
    BODY.2.NAME                   := 'ARM.LFR'
    SPRING.CONSTANT               := '0.0'
    FREE.LENGTH.SPRING            := '0.0'
    DAMPING.COEFFICIENT           := '0.0'
    ACTUATOR.FORCE                := '0.0'
    P.ON.BODY.1                   := ( 19.598, -33.685, 43.492 )
    P.ON.BODY.2                   := ( 21.415, -33.953, 29.259 )
    Q.ON.BODY.1                   := ( 19.598, -33.685, 44.492 )
    Q.ON.BODY.2                   := ( 21.415, -33.953, 30.259 )
    R.ON.BODY.1                   := ( 20.598, -33.685, 43.492 )
    R.ON.BODY.2                   := ( 22.415, -33.953, 29.259 )
    CURVE.SPRING                  := 'NONE'
    CURVE.DAMPER                  := 'NONE'
    CURVE.ACTUATOR                := 'NONE'
    NODE.1                        := '0'
    NODE.2                        := '0'
UP
CREATE TSDA
    NAME                          := 'SHOCK.RL'
    BODY.1.NAME                   := 'CHASSIS'
    BODY.2.NAME                   := 'ARM.LRL'
    SPRING.CONSTANT               := '0.0'
    FREE.LENGTH.SPRING            := '0.0'
    DAMPING.COEFFICIENT           := '0.0'
    ACTUATOR.FORCE                := '0.0'
    P.ON.BODY.1                   := ( -19.598, -174.865, 43.492 )
    P.ON.BODY.2                   := ( -21.415, -174.597, 29.259 )
    Q.ON.BODY.1                   := ( -19.598, -174.865, 44.492 )
    Q.ON.BODY.2                   := ( -21.415, -174.597, 30.259 )
    R.ON.BODY.1                   := ( -18.598, -174.865, 43.492 )
    R.ON.BODY.2                   := ( -20.415, -174.597, 29.259 )
    CURVE.SPRING                  := 'NONE'
    CURVE.DAMPER                  := 'NONE'
    CURVE.ACTUATOR                := 'NONE'
    NODE.1                        := '0'
    NODE.2                        := '0'
UP
CREATE TSDA
    NAME                          := 'SHOCK.RR'
    BODY.1.NAME                   := 'CHASSIS'
    BODY.2.NAME                   := 'ARM.LRR'
    SPRING.CONSTANT               := '0.0'
    FREE.LENGTH.SPRING            := '0.0'
    DAMPING.COEFFICIENT           := '0.0'
    ACTUATOR.FORCE                := '0.0'
    P.ON.BODY.1                   := ( 19.598, -174.865, 43.492 )
    P.ON.BODY.2                   := ( 21.415, -174.597, 29.259 )
    Q.ON.BODY.1                   := ( 19.598, -174.865, 44.492 )
    Q.ON.BODY.2                   := ( 21.415, -174.597, 30.259 )
    R.ON.BODY.1                   := ( 20.598, -174.865, 43.492 )
```

```
    R.ON.BODY.2                          := ( 22.415, -174.597, 29.259 )
    CURVE.SPRING                         := 'NONE'
    CURVE.DAMPER                         := 'NONE'
    CURVE.ACTUATOR                       := 'NONE'
    NODE.1                               := '0'
    NODE.2                               := '0'
UP
UP
JOINTS
CREATE REVOLUTE.JOINT
    NAME                                 := 'REV.LFL'
    BODY.1.NAME                          := 'CHASSIS'
    BODY.2.NAME                          := 'ARM.LFL'
    P.ON.BODY.1                          := ( -12.09, -37.78, 30.770 )
    P.ON.BODY.2                          := ( -12.09, -37.78, 30.770 )
    Q.ON.BODY.1                          := ( -12.09, -36.78, 30.770 )
    Q.ON.BODY.2                          := ( -12.09, -36.78, 30.770 )
    R.ON.BODY.1                          := ( -11.09, -37.78, 30.770 )
    R.ON.BODY.2                          := ( -11.09, -37.78, 30.770 )
    NODE.1                               := '0'
    NODE.2                               := '0'
UP
CREATE REVOLUTE.JOINT
    NAME                                 := 'REV.LFR'
    BODY.1.NAME                          := 'CHASSIS'
    BODY.2.NAME                          := 'ARM.LFR'
    P.ON.BODY.1                          := ( 12.09, -37.78, 30.770 )
    P.ON.BODY.2                          := ( 12.09, -37.78, 30.770 )
    Q.ON.BODY.1                          := ( 12.09, -36.78, 30.770 )
    Q.ON.BODY.2                          := ( 12.09, -36.78, 30.770 )
    R.ON.BODY.1                          := ( 13.09, -37.78, 30.770 )
    R.ON.BODY.2                          := ( 13.09, -37.78, 30.770 )
    NODE.1                               := '0'
    NODE.2                               := '0'
UP
CREATE REVOLUTE.JOINT
    NAME                                 := 'REV.LRL'
    BODY.1.NAME                          := 'CHASSIS'
    BODY.2.NAME                          := 'ARM.LRL'
    P.ON.BODY.1                          := ( -12.09, -170.77, 30.770 )
    P.ON.BODY.2                          := ( -12.09, -170.77, 30.770 )
    Q.ON.BODY.1                          := ( -12.09, -169.77, 30.770 )
    Q.ON.BODY.2                          := ( -12.09, -169.77, 30.770 )
    R.ON.BODY.1                          := ( -11.09, -170.77, 30.770 )
    R.ON.BODY.2                          := ( -11.09, -170.77, 30.770 )
    NODE.1                               := '0'
    NODE.2                               := '0'
UP
CREATE REVOLUTE.JOINT
    NAME                                 := 'REV.LRR'
    BODY.1.NAME                          := 'CHASSIS'
    BODY.2.NAME                          := 'ARM.LRR'
    P.ON.BODY.1                          := ( 12.09, -170.77, 30.770 )
      ON.BODY.2                          := ( 12.09, -170.77, 30.770 )
```

```
    Q.ON.BODY.1                          := ( 12.09, -169.77, 30.770 )
    Q.ON.BODY.2                          := ( 12.09, -169.77, 30.770 )
    R.ON.BODY.1                          := ( 13.09, -170.77, 30.770 )
    R.ON.BODY.2                          := ( 13.09, -170.77, 30.770 )
    NODE.1                               := '0'
    NODE.2                               := '0'
UP
CREATE REVOLUTE.JOINT
    NAME                                 := 'REV.UFL'
    BODY.1.NAME                          := 'CHASSIS'
    BODY.2.NAME                          := 'ARM.UFL'
    P.ON.BODY.1                          := ( -18.183, -44.003, 39.435 )
    P.ON.BODY.2                          := ( -18.183, -44.003, 39.435 )
    Q.ON.BODY.1                          := ( -17.558, -39.670, 40.400 )
    Q.ON.BODY.2                          := ( -17.558, -39.670, 40.400 )
    R.ON.BODY.1                          := ( -17.193, -44.146, 39.435 )
    R.ON.BODY.2                          := ( -17.193, -44.146, 39.435 )
    NODE.1                               := '0'
    NODE.2                               := '0'
UP
CREATE REVOLUTE.JOINT
    NAME                                 := 'REV.UFR'
    BODY.1.NAME                          := 'CHASSIS'
    BODY.2.NAME                          := 'ARM.UFR'
    P.ON.BODY.1                          := ( 18.183, -44.003, 39.435 )
    P.ON.BODY.2                          := ( 18.183, -44.003, 39.435 )
    Q.ON.BODY.1                          := ( 17.558, -39.670, 40.400 )
    Q.ON.BODY.2                          := ( 17.558, -39.670, 40.400 )
    R.ON.BODY.1                          := ( 19.173, -43.860, 39.435 )
    R.ON.BODY.2                          := ( 19.173, -43.860, 39.435 )
    NODE.1                               := '0'
    NODE.2                               := '0'
UP
CREATE REVOLUTE.JOINT
    NAME                                 := 'REV.URL'
    BODY.1.NAME                          := 'CHASSIS'
    BODY.2.NAME                          := 'ARM.URL'
    P.ON.BODY.1                          := ( -18.195, -162.380, 39.655 )
    P.ON.BODY.2                          := ( -18.195, -162.380, 39.655 )
    Q.ON.BODY.1                          := ( -18.195, -161.380, 39.655 )
    Q.ON.BODY.2                          := ( -18.195, -161.380, 39.655 )
    R.ON.BODY.1                          := ( -17.195, -162.380, 39.655 )
    R.ON.BODY.2                          := ( -17.195, -162.380, 39.655 )
    NODE.1                               := '0'
    NODE.2                               := '0'
UP
CREATE REVOLUTE.JOINT
    NAME                                 := 'REV.URR'
    BODY.1.NAME                          := 'CHASSIS'
    BODY.2.NAME                          := 'ARM.URR'
    P.ON.BODY.1                          := ( 18.195, -162.380, 39.655 )
    P.ON.BODY.2                          := ( 18.195, -162.380, 39.655 )
    Q.ON.BODY.1                          := ( 18.195, -161.380, 39.655 )
    Q.ON.BODY.2                          := ( 18.195, -161.380, 39.655 )
```

```
    R.ON.BODY.1                         := ( 19.195, -162.380, 39.655 )
    R.ON.BODY.2                         := ( 19.195, -162.380, 39.655 )
    NODE.1                              := '0'
    NODE.2                              := '0'
UP
CREATE REVOLUTE.JOINT
    NAME                                := 'PITMAN.REV'
    BODY.1.NAME                         := 'CHASSIS'
    BODY.2.NAME                         := 'PITMAN.ARM'
    P.ON.BODY.1                         := ( -9.811, -55.355, 34.039 )
    P.ON.BODY.2                         := ( -9.811, -55.355, 34.039 )
    Q.ON.BODY.1                         := ( -9.811, -55.038, 34.987 )
    Q.ON.BODY.2                         := ( -9.811, -55.038, 34.987 )
    R.ON.BODY.1                         := ( -8.811, -55.355, 34.039 )
    R.ON.BODY.2                         := ( -8.811, -55.355, 34.039 )
    NODE.1                              := '0'
    NODE.2                              := '0'
UP
CREATE REV-SPHR.JOINT
    NAME                                := 'IDLER.ARM'
    REV.BODY.1.NAME                     := 'CHASSIS'
    SPHR.BODY.2.NAME                    := 'STEERING.LINK'
    P.ON.BODY.1                         := ( 12.803, -55.355, 34.039 )
    P.ON.BODY.2                         := ( 12.803, -50.556, 32.433 )
    Q.ON.BODY.1                         := ( 12.803, -55.038, 34.987 )
    Q.ON.BODY.2                         := ( 12.803, -50.239, 33.381 )
    R.ON.BODY.1                         := ( 13.803, -55.355, 34.039 )
    R.ON.BODY.2                         := ( 13.803, -50.556, 32.433 )
    DISTANCE                            := '5.06'
UP
CREATE SPHERICAL.JOINT
    NAME                                := 'SPH.LFL'
    BODY.1.NAME                         := 'ARM.LFL'
    BODY.2.NAME                         := 'WHEEL.FL'
    P.ON.BODY.1                         := ( -30.965, -39.180, 26.120 )
    P.ON.BODY.2                         := ( -30.965, -39.180, 26.120 )
    Q.ON.BODY.1                         := ( -30.757, -39.232, 27.097 )
    Q.ON.BODY.2                         := ( -28.170, -39.868, 39.254 )
    R.ON.BODY.1                         := ( -31.943, -39.180, 26.328 )
    R.ON.BODY.2                         := ( -44.099, -39.180, 28.915 )
    NODE.1                              := '0'
    NODE.2                              := '0'
UP
CREATE SPHERICAL.JOINT
    NAME                                := 'SPH.LFR'
    BODY.1.NAME                         := 'ARM.LFR'
    BODY.2.NAME                         := 'WHEEL.FR'
    P.ON.BODY.1                         := ( 30.965, -39.180, 26.120 )
    P.ON.BODY.2                         := ( 30.965, -39.180, 26.120 )
    Q.ON.BODY.1                         := ( 30.757, -39.232, 27.097 )
    Q.ON.BODY.2                         := ( 28.170, -39.868, 39.254 )
    R.ON.BODY.1                         := ( 31.943, -39.180, 26.328 )
    R.ON.BODY.2                         := ( 44.099, -39.180, 28.915 )
    NODE.1                              := '0'
```

```
      NODE.2                                 := '0'
   UP
   CREATE SPHERICAL.JOINT
      NAME                                   := 'SPH.LRL'
      BODY.1.NAME                            := 'ARM.LRL'
      BODY.2.NAME                            := 'WHEEL.RL'
      P.ON.BODY.1                            := ( -30.965, -169.370, 26.120 )
      P.ON.BODY.2                            := ( -30.965, -169.370, 26.120 )
      Q.ON.BODY.1                            := ( -30.757, -169.422, 27.097 )
      Q.ON.BODY.2                            := ( -28.170, -169.370, 39.270 )
      R.ON.BODY.1                            := ( -31.943, -169.370, 26.328 )
      R.ON.BODY.2                            := ( -44.115, -169.370, 28.915 )
      NODE.1                                 := '0'
      NODE.2                                 := '0'
   UP
   CREATE SPHERICAL.JOINT
      NAME                                   := 'SPH.LRR'
      BODY.1.NAME                            := 'ARM.LRR'
      BODY.2.NAME                            := 'WHEEL.RR'
      P.ON.BODY.1                            := ( 30.965, -169.370, 26.120 )
      P.ON.BODY.2                            := ( 30.965, -169.370, 26.120 )
      Q.ON.BODY.1                            := ( 30.757, -169.422, 27.097 )
      Q.ON.BODY.2                            := ( 28.170, -169.370, 39.270 )
      R.ON.BODY.1                            := ( 31.943, -169.370, 26.328 )
      R.ON.BODY.2                            := ( 44.115, -169.370, 28.915 )
      NODE.1                                 := '0'
      NODE.2                                 := '0'
   UP
   CREATE SPHERICAL.JOINT
      NAME                                   := 'SPH.UFL'
      BODY.1.NAME                            := 'ARM.UFL'
      BODY.2.NAME                            := 'WHEEL.FL'
      P.ON.BODY.1                            := ( -28.170, -39.868, 39.254 )
      P.ON.BODY.2                            := ( -28.170, -39.868, 39.254 )
      Q.ON.BODY.1                            := ( -27.962, -39.920, 40.231 )
      Q.ON.BODY.2                            := ( -25.375, -40.556, 52.388 )
      R.ON.BODY.1                            := ( -29.148, -39.868, 39.462 )
      R.ON.BODY.2                            := ( -41.304, -39.868, 42.049 )
      NODE.1                                 := '0'
      NODE.2                                 := '0'
   UP
   CREATE SPHERICAL.JOINT
      NAME                                   := 'SPH.UFR'
      BODY.1.NAME                            := 'ARM.UFR'
      BODY.2.NAME                            := 'WHEEL.FR'
      P.ON.BODY.1                            := ( 28.170, -39.868, 39.254 )
      P.ON.BODY.2                            := ( 28.170, -39.868, 39.254 )
      Q.ON.BODY.1                            := ( 27.962, -39.920, 40.231 )
      Q.ON.BODY.2                            := ( 25.375, -40.556, 52.388 )
      R.ON.BODY.1                            := ( 29.148, -39.868, 39.462 )
      R.ON.BODY.2                            := ( 41.304, -39.868, 42.049 )
      NODE.1                                 := '0'
      NODE.2                                 := '0'
   UP
```

```
CREATE SPHERICAL.JOINT
    NAME                        := 'SPH.URL'
    BODY.1.NAME                 := 'ARM.URL'
    BODY.2.NAME                 := 'WHEEL.RL'
    P.ON.BODY.1                 := ( -28.170, -169.370, 39.270 )
    P.ON.BODY.2                 := ( -28.170, -169.370, 39.270 )
    Q.ON.BODY.1                 := ( -25.375, -169.370, 52.420 )
    Q.ON.BODY.2                 := ( -25.375, -169.370, 52.420 )
    R.ON.BODY.1                 := ( -41.320, -169.370, 42.065 )
    R.ON.BODY.2                 := ( -41.320, -169.370, 42.065 )
    NODE.1                      := '0'
    NODE 2                      := '0'
UP
CREATE SPHERICAL.JOINT
    NAME                        := 'SPH.URR'
    BODY.1.NAME                 := 'ARM.URR'
    BODY.2.NAME                 := 'WHEEL.RR'
    P.ON.BODY.1                 := ( 28.170, -169.370, 39.270 )
    P.ON.BODY.2                 := ( 28.170, -169.370, 39.270 )
    Q.ON.BODY.1                 := ( 25.375, -169.370, 52.420 )
    Q.ON.BODY.2                 := ( 25.375, -169.370, 52.420 )
    R.ON.BODY.1                 := ( 41.320, -169.370, 42.065 )
    R.ON.BODY.2                 := ( 41.320, -169.370, 42.065 )
    NODE.1                      := '0'
    NODE.2                      := '0'
UP
CREATE UNIVERSAL.JOINT
    NAME                        := 'PITMAN.UNIV'
    BODY.1.NAME                 := 'PITMAN.ARM'
    BODY.2.NAME                 := 'STEERING.LINK'
    P.ON.BODY.1                 := ( -9.811, -50.556, 32.433 )
    P.ON.BODY.2                 := ( -9.811, -50.556, 32.433 )
    Q.ON.BODY.1                 := ( -9.811, -50.239, 33.381 )
    Q.ON.BODY.2                 := ( -9.811, -49.608, 32.116 )
    R.ON.BODY.1                 := ( -8.811, -50.556, 32.433 )
    R.ON.BODY.2                 := ( -8.811, -50.556, 32.433 )
    NODE.1                      := '0'
    NODE.2                      := '0'
UP
UP
CREATE BODY
    NAME                        := 'CHASSIS'
    CENTER.OF.GRAVITY           := ( 0.585, -123.170, 63.064 )
    TYPE.ANGULAR.COORD          := 'BRYANT'
    ANGLE.1                     := '0.0'
    ANGLE.2                     := '0.0'
    ANGLE.3                     := '0.0'
    FIXED.TO.GROUND             := 'FALSE'
    MASS                        := '20.049'
    INERTIA.XXL                 := '52680.0'
    INERTIA.YYL                 := '13320.0'
    INERTIA.ZZL                 := '56280.0'
    INERTIA.XYL                 := '0.0'
    INERTIA.XZL                 := '0.0'
```

```
    INERTIA.YZL                         := '0.0'
    XG.FORCE                            := '0.0'
    YG.FORCE                            := '0.0'
    ZG.FORCE                            := '0.0'
    XL.TORQUE                           := '0.0'
    YL.TORQUE                           := '0.0'
    ZL.TORQUE                           := '0.0'
    CURVE.XGF                           := 'NONE'
    CURVE.YGF                           := 'NONE'
    CURVE.ZGF                           := 'NONE'
    CURVE.XLT                           := 'NONE'
    CURVE.YLT                           := 'NONE'
    CURVE.ZLT                           := 'NONE'
    SIGN.EO                             := 'POSITIVE'
    ANGULAR.UNITS                       := 'DEGREES'
    FLEXIBLE                            := 'FALSE'
    SUPERELEMENT                        := 'FALSE'
UP
CREATE BODY
    NAME                                := 'ARM.LFL'
    CENTER.OF.GRAVITY                   := ( -21.5275, -37.78, 28.445 )
    TYPE.ANGULAR.COORD                  := 'BRYANT'
    ANGLE.1                             := '0.0'
    ANGLE.2                             := '-13.84'
    ANGLE.3                             := '0.0'
    FIXED.TO.GROUND                     := 'FALSE'
    MASS                                := '0.0932'
    INERTIA.XXL                         := '1.0'
    INERTIA.YYL                         := '1.0'
    INERTIA.ZZL                         := '1.0'
    INERTIA.XYL                         := '0.0'
    INERTIA.XZL                         := '0.0'
    INERTIA.YZL                         := '0.0'
    XG.FORCE                            := '0.0'
    YG.FORCE                            := '0.0'
    ZG.FORCE                            := '0.0'
    XL.TORQUE                           := '0.0'
    YL.TORQUE                           := '0.0'
    ZL.TORQUE                           := '0.0'
    CURVE.XGF                           := 'NONE'
    CURVE.YGF                           := 'NONE'
    CURVE.ZGF                           := 'NONE'
    CURVE.XLT                           := 'NONE'
    CURVE.YLT                           := 'NONE'
    CURVE.ZLT                           := 'NONE'
    SIGN.EO                             := 'POSITIVE'
    ANGULAR.UNITS                       := 'DEGREES'
    FLEXIBLE                            := 'FALSE'
    SUPERELEMENT                        := 'FALSE'
UP
CREATE BODY
    NAME                                := 'ARM.LFR'
    CENTER.OF.GRAVITY                   := ( 21.5275, -37.78, 28.445 )
    TYPE.ANGULAR.COORD                  := 'BRYANT'
```

```
      ANGLE.1                         := '0.0'
      ANGLE.2                         := '13.84'
      ANGLE.3                         := '0.0'
      FIXED.TO.GROUND                 := 'FALSE'
      MASS                            := '0.0932'
      INERTIA.XXL                     := '1.0'
      INERTIA.YYL                     := '1.0'
      INERTIA.ZZL                     := '1.0'
      INERTIA.XYL                     := '0.0'
      INERTIA.XZL                     := '0.0'
      INERTIA.YZL                     := '0.0'
      XG.FORCE                        := '0.0'
      YG.FORCE                        := '0.0'
      ZG.FORCE                        := '0.0'
      XL.TORQUE                       := '0.0'
      YL.TORQUE                       := '0.0'
      ZL.TORQUE                       := '0.0'
      CURVE.XGF                       := 'NONE'
      CURVE.YGF                       := 'NONE'
      CURVE.ZGF                       := 'NONE'
      CURVE.XLT                       := 'NONE'
      CURVE.YLT                       := 'NONE'
      CURVE.ZLT                       := 'NONE'
      SIGN.EO                         := 'POSITIVE'
      ANGULAR.UNITS                   := 'DEGREES'
      FLEXIBLE                        := 'FALSE'
      SUPERELEMENT                    := 'FALSE'
   UP
   CREATE BODY
      NAME                            := 'ARM.LRL'
      CENTER.OF.GRAVITY               := ( -21.5275, -170.77, 28.445 )
      TYPE.ANGULAR.COORD              := 'BRYANT'
      ANGLE.1                         := '0.0'
      ANGLE.2                         := '-13.84'
      ANGLE.3                         := '0.0'
      FIXED.TO.GROUND                 := 'FALSE'
      MASS                            := '0.0932'
      INERTIA.XXL                     := '1.0'
      INERTIA.YYL                     := '1.0'
      INERTIA.ZZL                     := '1.0'
      INERTIA.XYL                     := '0.0'
      INERTIA.XZL                     := '0.0'
      INERTIA.YZL                     := '0.0'
      XG.FORCE                        := '0.0'
      YG.FORCE                        := '0.0'
      ZG.FORCE                        := '0.0'
      XL.TORQUE                       := '0.0'
      YL.TORQUE                       := '0.0'
      ZL.TORQUE                       := '0.0'
      CURVE.XGF                       := 'NONE'
      CURVE.YGF                       := 'NONE'
      CURVE.ZGF                       := 'NONE'
      CURVE.XLT                       := 'NONE'
      CURVE.YLT                       := 'NONE'
```

```
      CURVE.ZLT                          := 'NONE'
      SIGN.EO                            := 'POSITIVE'
      ANGULAR.UNITS                      := 'DEGREES'
      FLEXIBLE                           := 'FALSE'
      SUPERELEMENT                       := 'FALSE'
   UP
   CREATE BODY
      NAME                               := 'ARM.LRR'
      CENTER.OF.GRAVITY                  := ( 21.5275, -170.77, 28.445 )
      TYPE.ANGULAR.COORD                 := 'BRYANT'
      ANGLE.1                            := '0.0'
      ANGLE.2                            := '13.84'
      ANGLE.3                            := '0.0'
      FIXED.TO.GROUND                    := 'FALSE'
      MASS                               := '0.0932'
      INERTIA.XXL                        := '1.0'
      INERTIA.YYL                        := '1.0'
      INERTIA.ZZL                        := '1.0'
      INERTIA.XYL                        := '0.0'
      INERTIA.XZL                        := '0.0'
      INERTIA.YZL                        := '0.0'
      XG.FORCE                           := '0.0'
      YG.FORCE                           := '0.0'
      ZG.FORCE                           := '0.0'
      XL.TORQUE                          := '0.0'
      YL.TORQUE                          := '0.0'
      ZL.TORQUE                          := '0.0'
      CURVE.XGF                          := 'NONE'
      CURVE.YGF                          := 'NONE'
      CURVE.ZGF                          := 'NONE'
      CURVE.XLT                          := 'NONE'
      CURVE.YLT                          := 'NONE'
      CURVE.ZLT                          := 'NONE'
      SIGN.EO                            := 'POSITIVE'
      ANGULAR.UNITS                      := 'DEGREES'
      FLEXIBLE                           := 'FALSE'
      SUPERELEMENT                       := 'FALSE'
   UP
   CREATE BODY
      NAME                               := 'ARM.UFL'
      CENTER.OF.GRAVITY                  := ( -23.1765, -41.935, 39.3445 )
      TYPE.ANGULAR.COORD                 := 'BRYANT'
      ANGLE.1                            := '12.557'
      ANGLE.2                            := '0.0'
      ANGLE.3                            := '-8.209'
      FIXED.TO.GROUND                    := 'FALSE'
      MASS                               := '0.0311'
      INERTIA.XXL                        := '1.0'
      INERTIA.YYL                        := '1.0'
      INERTIA.ZZL                        := '1.0'
      INERTIA.XYL                        := '0.0'
      INERTIA.XZL                        := '0.0'
      INERTIA.YZL                        := '0.0'
      XG.FORCE                           := '0.0'
```

```
    YG.FORCE                          := '0.0'
    ZG.FORCE                          := '0.0'
    XL.TORQUE                         := '0.0'
    YL.TORQUE                         := '0.0'
    ZL.TORQUE                         := '0.0'
    CURVE.XGF                         := 'NONE'
    CURVE.YGF                         := 'NONE'
    CURVE.ZGF                         := 'NONE'
    CURVE.XLT                         := 'NONE'
    CURVE.YLT                         := 'NONE'
    CURVE.ZLT                         := 'NONE'
    SIGN.EO                           := 'POSITIVE'
    ANGULAR.UNITS                     := 'DEGREES'
    FLEXIBLE                          := 'FALSE'
    SUPERELEMENT                      := 'FALSE'
UP
CREATE BODY
    NAME                              := 'ARM.UFR'
    CENTER.OF.GRAVITY                 := ( 23.1765, -41.935, 39.3445 )
    TYPE.ANGULAR.COORD                := 'BRYANT'
    ANGLE.1                           := '12.557'
    ANGLE.2                           := '0.0'
    ANGLE.3                           := '8.209'
    FIXED.TO.GROUND                   := 'FALSE'
    MASS                              := '0.0311'
    INERTIA.XXL                       := '1.0'
    INERTIA.YYL                       := '1.0'
    INERTIA.ZZL                       := '1.0'
    INERTIA.XYL                       := '0.0'
    INERTIA.XZL                       := '0.0'
    INERTIA.YZL                       := '0.0'
    XG.FORCE                          := '0.0'
    YG.FORCE                          := '0.0'
    ZG.FORCE                          := '0.0'
    XL.TORQUE                         := '0.0'
    YL.TORQUE                         := '0.0'
    ZL.TORQUE                         := '0.0'
    CURVE.XGF                         := 'NONE'
    CURVE.YGF                         := 'NONE'
    CURVE.ZGF                         := 'NONE'
    CURVE.XLT                         := 'NONE'
    CURVE.YLT                         := 'NONE'
    CURVE.ZLT                         := 'NONE'
    SIGN.EO                           := 'POSITIVE'
    ANGULAR.UNITS                     := 'DEGREES'
    FLEXIBLE                          := 'FALSE'
    SUPERELEMENT                      := 'FALSE'
UP
CREATE BODY
    NAME                              := 'ARM.URL'
    CENTER.OF.GRAVITY                 := ( -23.1825, -165.875, 39.4625 )
    TYPE.ANGULAR.COORD                := 'BRYANT'
    ANGLE.1                           := '0.0'
    ANGLE.2                           := '-2.21'
```

```
    ANGLE.3                        := '0.0'
    FIXED.TO.GROUND                := 'FALSE'
    MASS                           := '0.0311'
    INERTIA.XXL                    := '1.0'
    INERTIA.YYL                    := '1.0'
    INERTIA.ZZL                    := '1.0'
    INERTIA.XYL                    := '0.0'
    INERTIA.XZL                    := '0.0'
    INERTIA.YZL                    := '0.0'
    XG.FORCE                       := '0.0'
    YG.FORCE                       := '0.0'
    ZG.FORCE                       := '0.0'
    XL.TORQUE                      := '0.0'
    YL.TORQUE                      := '0.0'
    ZL.TORQUE                      := '0.0'
    CURVE.XGF                      := 'NONE'
    CURVE.YGF                      := 'NONE'
    CURVE.ZGF                      := 'NONE'
    CURVE.XLT                      := 'NONE'
    CURVE.YLT                      := 'NONE'
    CURVE.ZLT                      := 'NONE'
    SIGN.EO                        := 'POSITIVE'
    ANGULAR.UNITS                  := 'DEGREES'
    FLEXIBLE                       := 'FALSE'
    SUPERELEMENT                   := 'FALSE'
UP
CREATE BODY
    NAME                           := 'ARM.URR'
    CENTER.OF.GRAVITY              := ( 23.1825, -163.875, 39.4625 )
    TYPE.ANGULAR.COORD             := 'BRYANT'
    ANGLE.1                        := '0.0'
    ANGLE.2                        := '2.21'
    ANGLE.3                        := '0.0'
    FIXED.TO.GROUND                := 'FALSE'
    MASS                           := '0.0311'
    INERTIA.XXL                    := '1.0'
    INERTIA.YYL                    := '1.0'
    INERTIA.ZZL                    := '1.0'
    INERTIA.XYL                    := '0.0'
    INERTIA.XZL                    := '0.0'
    INERTIA.YZL                    := '0.0'
    XG.FORCE                       := '0.0'
    YG.FORCE                       := '0.0'
    ZG.FORCE                       := '0.0'
    XL.TORQUE                      := '0.0'
    YL.TORQUE                      := '0.0'
    ZL.TORQUE                      := '0.0'
    CURVE.XGF                      := 'NONE'
    CURVE.YGF                      := 'NONE'
    CURVE.ZGF                      := 'NONE'
    CURVE.XLT                      := 'NONE'
    CURVE.YLT                      := 'NONE'
    CURVE.ZLT                      := 'NONE'
    SIGN.EO                        := 'POSITIVE'
```

```
    ANGULAR.UNITS                  := 'DEGREES'
    FLEXIBLE                       := 'FALSE'
    SUPERELEMENT                   := 'FALSE'
UP
CREATE BODY
    NAME                           := 'WHEEL.FL'
    CENTER.OF.GRAVITY              := ( -35.815, -39.37, 29.735 )
    TYPE.ANGULAR.COORD             := 'BRYANT'
    ANGLE.1                        := '0.0'
    ANGLE.2                        := '0.0'
    ANGLE.3                        := '-0.246'
    FIXED.TO.GROUND                := 'FALSE'
    MASS                           := '0.5047'
    INERTIA.XXL                    := '1.0'
    INERTIA.YYL                    := '1.0'
    INERTIA.ZZL                    := '1.0'
    INERTIA.XYL                    := '0.0'
    INERTIA.XZL                    := '0.0'
    INERTIA.YZL                    := '0.0'
    XG.FORCE                       := '0.0'
    YG.FORCE                       := '0.0'
    ZG.FORCE                       := '0.0'
    XL.TORQUE                      := '0.0'
    YL.TORQUE                      := '0.0'
    ZL.TORQUE                      := '0.0'
    CURVE.XGF                      := 'NONE'
    CURVE.YGF                      := 'NONE'
    CURVE.ZGF                      := 'NONE'
    CURVE.XLT                      := 'NONE'
    CURVE.YLT                      := 'NONE'
    CURVE.ZLT                      := 'NONE'
    SIGN.EO                        := 'POSITIVE'
    ANGULAR.UNITS                  := 'DEGREES'
    FLEXIBLE                       := 'FALSE'
    SUPERELEMENT                   := 'FALSE'
UP
CREATE BODY
    NAME                           := 'WHEEL.FR'
    CENTER.OF.GRAVITY              := ( 35.815, -39.37, 29.735 )
    TYPE.ANGULAR.COORD             := 'BRYANT'
    ANGLE.1                        := '0.0'
    ANGLE.2                        := '0.0'
    ANGLE.3                        := '0.246'
    FIXED.TO.GROUND                := 'FALSE'
    MASS                           := '0.5047'
    INERTIA.XXL                    := '1.0'
    INERTIA.YYL                    := '1.0'
    INERTIA.ZZL                    := '1.0'
    INERTIA.XYL                    := '0.0'
    INERTIA.XZL                    := '0.0'
    INERTIA.YZL                    := '0.0'
    XG.FORCE                       := '0.0'
    YG.FORCE                       := '0.0'
    ZG.FORCE                       := '0.0'
```

```
    XL.TORQUE                          := '0.0'
    YL.TORQUE                          := '0.0'
    ZL.TORQUE                          := '0.0'
    CURVE.XGF                          := 'NONE'
    CURVE.YGF                          := 'NONE'
    CURVE.ZGF                          := 'NONE'
    CURVE.XLT                          := 'NONE'
    CURVE.YLT                          := 'NONE'
    CURVE.ZLT                          := 'NONE'
    SIGN.EO                            := 'POSITIVE'
    ANGULAR.UNITS                      := 'DEGREES'
    FLEXIBLE                           := 'FALSE'
    SUPERELEMENT                       := 'FALSE'
UP
CREATE BODY
    NAME                               := 'WHEEL.RL'
    CENTER.OF.GRAVITY                  := ( -35.815, -169.37, 29.735 )
    TYPE.ANGULAR.COORD                 := 'BRYANT'
    ANGLE.1                            := '0.0'
    ANGLE.2                            := '0.0'
    ANGLE.3                            := '0.246'
    FIXED.TO.GROUND                    := 'FALSE'
    MASS                               := '0.5046'
    INERTIA.XXL                        := '1.0'
    INERTIA.YYL                        := '1.0'
    INERTIA.ZZL                        := '1.0'
    INERTIA.XYL                        := '0.0'
    INERTIA.XZL                        := '0.0'
    INERTIA.YZL                        := '0.0'
    XG.FORCE                           := '0.0'
    YG.FORCE                           := '0.0'
    ZG.FORCE                           := '0.0'
    XL.TORQUE                          := '0.0'
    YL.TORQUE                          := '0.0'
    ZL.TORQUE                          := '0.0'
    CURVE.XGF                          := 'NONE'
    CURVE.YGF                          := 'NONE'
    CURVE.ZGF                          := 'NONE'
    CURVE.XLT                          := 'NONE'
    CURVE.YLT                          := 'NONE'
    CURVE.ZLT                          := 'NONE'
    SIGN.EO                            := 'POSITIVE'
    ANGULAR.UNITS                      := 'DEGREES'
    FLEXIBLE                           := 'FALSE'
    SUPERELEMENT                       := 'FALSE'
UP
CREATE BODY
    NAME                               := 'WHEEL.RR'
    CENTER.OF.GRAVITY                  := ( 35.815, -169.37, 29.735 )
    TYPE.ANGULAR.COORD                 := 'BRYANT'
    ANGLE.1                            := '0.0'
    ANGLE.2                            := '0.0'
    ANGLE.3                            := '-0.246'
    FIXED.TO.GROUND                    := 'FALSE'
```

```
      MASS                          := '0.5046'
      INERTIA.XXL                   := '1.0'
      INERTIA.YYL                   := '1.0'
      INERTIA.ZZL                   := '1.0'
      INERTIA.XYL                   := '0.0'
      INERTIA.XZL                   := '0.0'
      INERTIA.YZL                   := '0.0'
      XG.FORCE                      := '0.0'
      YG.FORCE                      := '0.0'
      ZG.FORCE                      := '0.0'
      XL.TORQUE                     := '0.0'
      YL.TORQUE                     := '0.0'
      ZL.TORQUE                     := '0.0'
      CURVE.XGF                     := 'NONE'
      CURVE.YGF                     := 'NONE'
      CURVE.ZGF                     := 'NONE'
      CURVE.XLT                     := 'NONE'
      CURVE.YLT                     := 'NONE'
      CURVE.ZLT                     := 'NONE'
      SIGN.EO                       := 'POSITIVE'
      ANGULAR.UNITS                 := 'DEGREES'
      FLEXIBLE                      := 'FALSE'
      SUPERELEMENT                  := 'FALSE'
   UP
   CREATE BODY
      NAME                          := 'PITMAN.ARM'
      CENTER.OF.GRAVITY             := ( -9.811, -52.956, 33.236 )
      TYPE.ANGULAR.COORD            := 'BRYANT'
      ANGLE.1                       := '-18.5'
      ANGLE.2                       := '0.0'
      ANGLE.3                       := '0.0'
      FIXED.TO.GROUND               := 'FALSE'
      MASS                          := '0.0129'
      INERTIA.XXL                   := '1.0'
      INERTIA.YYL                   := '1.0'
      INERTIA.ZZL                   := '1.0'
      INERTIA.XYL                   := '0.0'
      INERTIA.XZL                   := '0.0'
      INERTIA.YZL                   := '0.0'
      XG.FORCE                      := '0.0'
      YG.FORCE                      := '0.0'
      ZG.FORCE                      := '0.0'
      XL.TORQUE                     := '0.0'
      YL.TORQUE                     := '0.0'
      ZL.TORQUE                     := '0.0'
      CURVE.XGF                     := 'NONE'
      CURVE.YGF                     := 'NONE'
      CURVE.ZGF                     := 'NONE'
      CURVE.XLT                     := 'NONE'
      CURVE.YLT                     := 'NONE'
      CURVE.ZLT                     := 'NONE'
      SIGN.EO                       := 'POSITIVE'
      ANGULAR.UNITS                 := 'DEGREES'
      FLEXIBLE                      := 'FALSE'
```

```
    SUPERELEMENT                          := 'FALSE'
UP
CREATE BODY
    NAME                                  := 'STEERING.LINK'
    CENTER.OF.GRAVITY                     := ( 0.000, -50.556, 32.433 )
    TYPE.ANGULAR.COORD                    := 'BRYANT'
    ANGLE.1                               := '-18.5'
    ANGLE.2                               := '0.0'
    ANGLE.3                               := '0.0'
    FIXED.TO.GROUND                       := 'FALSE'
    MASS                                  := '.0518'
    INERTIA.XXL                           := '1.0'
    INERTIA.YYL                           := '1.0'
    INERTIA.ZZL                           := '1.0'
    INERTIA.XYL                           := '0.0'
    INERTIA.XZL                           := '0.0'
    INERTIA.YZL                           := '0.0'
    XG.FORCE                              := '0.0'
    YG.FORCE                              := '0.0'
    ZG.FORCE                              := '0.0'
    XL.TORQUE                             := '0.0'
    YL.TORQUE                             := '0.0'
    ZL.TORQUE                             := '0.0'
    CURVE.XGF                             := 'NONE'
    CURVE.YGF                             := 'NONE'
    CURVE.ZGF                             := 'NONE'
    CURVE.XLT                             := 'NONE'
    CURVE.YLT                             := 'NONE'
    CURVE.ZLT                             := 'NONE'
    SIGN.EO                               := 'POSITIVE'
    ANGULAR.UNITS                         := 'DEGREES'
    FLEXIBLE                              := 'FALSE'
    SUPERELEMENT                          := 'FALSE'
UP
CREATE INITIAL.CONDITION
    NAME                                  := 'INIT.CHASSIS.ORIEN'
    BODY.1.NAME                           := 'CHASSIS'
    BODY.2.NAME                           := 'NONE'
    ELEMENT.NAME                          := 'NONE'
    TYPE.INITIAL.COND                     := 'ORIENTATION'
    INITIAL.VALUE                         := '0.0'
    TIME.DERIVATIVE                       := '0.0'
    OMEGA.Y                               := '0.0'
    OMEGA.Z                               := '0.0'
    F.ON.BODY.1                           := ( 0.0, 0.0, 0.0 )
    F.ON.BODY.2                           := ( 0.0, 0.0, 0.0 )
    EXTRA.COORD                           := '0'
    ANGULAR.UNITS                         := 'DEGREES'
UP
CREATE INITIAL.CONDITION
    NAME                                  := 'INIT.CHASSIS.X'
    BODY.1.NAME                           := 'CHASSIS'
    BODY.2.NAME                           := 'NONE'
    ELEMENT.NAME                          := 'NONE'
```

```
    TYPE.INITIAL.COND                     := 'X'
    INITIAL.VALUE                         := '0.0'
    TIME.DERIVATIVE                       := '0.0'
    OMEGA.Y                               := '0.0'
    OMEGA.Z                               := '0.0'
    P.ON.BODY.1                           := ( 0.0, 0.0, 0.0 )
    P.ON.BODY.2                           := ( 0.0, 0.0, 0.0 )
    EXTRA.COORD                           := '0'
    ANGULAR.UNITS                         := 'DEGREES'
UP
CREATE INITIAL.CONDITION
    NAME                                  := 'INIT.CHASSIS.Y'
    BODY.1.NAME                           := 'CHASSIS'
    BODY.2.NAME                           := 'NONE'
    ELEMENT.NAME                          := 'NONE'
    TYPE.INITIAL.COND                     := 'Y'
    INITIAL.VALUE                         := '0.0'
    TIME.DERIVATIVE                       := '264.000'
    OMEGA.Y                               := '0.0'
    OMEGA.Z                               := '0.0'
    P.ON.BODY.1                           := ( 0.0, 0.0, 0.0 )
    P.ON.BODY.2                           := ( 0.0, 0.0, 0.0 )
    EXTRA.COORD                           := '0'
    ANGULAR.UNITS                         := 'DEGREES'
UP
CREATE INITIAL.CONDITION
    NAME                                  := 'INIT.CHASSIS.Z'
    BODY.1.NAME                           := 'CHASSIS'
    BODY.2.NAME                           := 'NONE'
    ELEMENT.NAME                          := 'NONE'
    TYPE.INITIAL.COND                     := 'Z'
    INITIAL.VALUE                         := '0.0'
    TIME.DERIVATIVE                       := '0.0'
    OMEGA.Y                               := '0.0'
    OMEGA.Z                               := '0.0'
    P.ON.BODY.1                           := ( 0.0, 0.0, 0.0 )
    P.ON.BODY.2                           := ( 0.0, 0.0, 0.0 )
    EXTRA.COORD                           := '0'
    ANGULAR.UNITS                         := 'DEGREES'
UP
CREATE INITIAL.CONDITION
    NAME                                  := 'INIT.WHEEL.FL'
    BODY.1.NAME                           := 'WHEEL.FL'
    BODY.2.NAME                           := 'NONE'
    ELEMENT.NAME                          := 'NONE'
    TYPE.INITIAL.COND                     := 'Z'
    INITIAL.VALUE                         := '0.0'
    TIME.DERIVATIVE                       := '0.0'
    OMEGA.Y                               := '0.0'
    OMEGA.Z                               := '0.0'
    P.ON.BODY.1                           := ( 0.0, 0.0, 0.0 )
    P.ON.BODY.2                           := ( 0.0, 0.0, 0.0 )
    EXTRA.COORD                           := '0'
    ANGULAR.UNITS                         := 'DEGREES'
```

```
UP
CREATE INITIAL.CONDITION
    NAME                    := 'INIT.WHEEL.FR'
    BODY.1.NAME             := 'WHEEL.FR'
    BODY.2.NAME             := 'NONE'
    ELEMENT.NAME            := 'NONE'
    TYPE.INITIAL.COND       := 'Z'
    INITIAL.VALUE           := '0.0'
    TIME.DERIVATIVE         := '0.0'
    OMEGA.Y                 := '0.0'
    OMEGA.Z                 := '0.0'
    P.ON.BODY.1             := ( 0.0, 0.0, 0.0 )
    P.ON.BODY.2             := ( 0.0, 0.0, 0.0 )
    EXTRA.COORD             := '0'
    ANGULAR.UNITS           := 'DEGREES'
UP
CREATE INITIAL.CONDITION
    NAME                    := 'INIT.WHEEL.RL'
    BODY.1.NAME             := 'WHEEL.RL'
    BODY.2.NAME             := 'NONE'
    ELEMENT.NAME            := 'NONE'
    TYPE.INITIAL.COND       := 'Z'
    INITIAL.VALUE           := '0.0'
    TIME.DERIVATIVE         := '0.0'
    OMEGA.Y                 := '0.0'
    OMEGA.Z                 := '0.0'
    P.ON.BODY.1             := ( 0.0, 0.0, 0.0 )
    P.ON.BODY.2             := ( 0.0, 0.0, 0.0 )
    EXTRA.COORD             := '0'
    ANGULAR.UNITS           := 'DEGREES'
UP
CREATE INITIAL.CONDITION
    NAME                    := 'INIT.WHEEL.RR'
    BODY.1.NAME             := 'WHEEL.RR'
    BODY.2.NAME             := 'NONE'
    ELEMENT.NAME            := 'NONE'
    TYPE.INITIAL.COND       := 'Z'
    INITIAL.VALUE           := '0.0'
    TIME.DERIVATIVE         := '0.0'
    OMEGA.Y                 := '0.0'
    OMEGA.Z                 := '0.0'
    P.ON.BODY.1             := ( 0.0, 0.0, 0.0 )
    P.ON.BODY.2             := ( 0.0, 0.0, 0.0 )
    EXTRA.COORD             := '0'
    ANGULAR.UNITS           := 'DEGREES'
UP
CREATE DRIVER
    NAME                    := 'DRIVER'
    BODY.1.NAME             := 'NONE'
    BODY.2.NAME             := 'NONE'
    TYPE.DRIVER             := 'REL.ANGLE'
    DRIVING.FUNCTION        := 'GENERAL'
    FUNCTION.PARAMETERS     := ( 0.0, 0.0, 0.0, 0.0 )
    P.ON.BODY.1             := ( 0.0, 0.0, 0.0 )
```

```
      P.ON.BODY.2                           := ( 0.0, 0.0, 0.0 )
      Q.ON.BODY.1                           := ( 0.0, 0.0, 1.0 )
      Q.ON.BODY.2                           := ( 0.0, 0.0, 1.0 )
      R.ON.BODY.1                           := ( 1.0, 0.0, 0.0 )
      R.ON.BODY.2                           := ( 1.0, 0.0, 0.0 )
      CURVE.DRIVER                          := 'TRAJECTORY'
      JOINT.NAME                            := 'PITMAN.REV'
      ANGULAR.UNITS                         := 'DEGREES'
   UP
   CREATE CURVE
      NAME                                  := 'TIRE.COEF'
      TYPE.DATA                             := 'PAIRED.XY'
      SLOPE.LEFT                            := '4.000'
      SLOPE.RIGHT                           := '0.000'
      SCALE.X                               := '1.0'
      SCALE.Y                               := '1.0'
      START.X                               := '0.0'
      INCREMENT.X                           := '0.0'
      INTERPOLATION                         := 'CUBIC'
      DATA
        0.00000000000000E+00 0.00000000000000E+00 0.20000000000000E-01 0.8000000000
        0.40000000000000E-01 0.20000000000000     0.80000000000000E-01 0.4950000000
        0.10500000000000     0.70000000000000     0.12500000000000     0.7600000000
        0.16500000000000     0.79500000000000     0.22000000000000     0.7950000000
        0.29500000000000     0.75000000000000     0.43000000000000     0.7000000000
         1.0000000000000     0.60000000000000
      ENDDATA
   UP
   CREATE CURVE
      NAME                                  := 'BIAS.TIRE.20PSI'
      TYPE.DATA                             := 'PAIRED.XY'
      SLOPE.LEFT                            := '666.7'
      SLOPE.RIGHT                           := '1600.000'
      SCALE.X                               := '1.0'
      SCALE.Y                               := '1.0'
      START.X                               := '0.0'
      INCREMENT.X                           := '0.0'
      INTERPOLATION                         := 'CUBIC'
      DATA
        0.00000000000000E+00 0.00000000000000E+00 0.10000000000000     66.67000000
        0.20000000000000     125.00000000000      0.30000000000000     175.0000000
        0.40000000000000     250.00000000000      0.50000000000000     375.0000000
        0.60000000000000     475.00000000000      0.70000000000000     600.0000000
        0.80000000000000     700.00000000000       1.0000000000000     975.0000000
         1.2000000000000     1250.0000000000       1.4000000000000     1500.000000
         1.6000000000000     1800.0000000000       1.8000000000000     2100.000000
         2.0000000000000     2425.0000000000       2.2000000000000     2700.000000
         2.4000000000000     3125.0000000000       2.6000000000000     3350.000000
         2.8000000000000     3675.0000000000       3.0000000000000     3975.000000
         3.2000000000000     4300.0000000000
      ENDDATA
```



```
   UP
   CREATE CURVE
      NAME                                  := 'BIAS.TIRE.30PSI'
```

```
    TYPE.DATA                                   := 'PAIRED.XY'
    SLOPE.LEFT                                  := '666.7'
    SLOPE.RIGHT                                 := '2125.000'
    SCALE.X                                     := '1.0'
    SCALE.Y                                     := '1.0'
    START.X                                     := '0.0'
    INCREMENT.X                                 := '0.0'
    INTERPOLATION                               := 'CUBIC'
    DATA
      0.00000000000000E+00 0.00000000000000E+00 0.1000000000000      66.6700000(
      0.2000000000000      150.0000000000       0.3000000000000      225.000000(
      0.4000000000000      325.0000000000       0.5000000000000      475.000000(
      0.6000000000000      600.0000000000       0.7000000000000      725.000000(
      0.8000000000000      900.0000000000        1.000000000000      1225.00000(
       1.200000000000      1600.000000000        1.400000000000      1950.00000(
       1.600000000000      2350.000000000        1.800000000000      2750.00000(
       2.000000000000      3150.000000000        2.200000000000      3550.00000(
       2.400000000000      3950.000000000        2.600000000000      4375.00000(
       2.800000000000      4300.000000000        3.000000000000      5225.00000(
       3.200000000000      5650.000000000
    ENDDATA
UP
CREATE CURVE
    NAME                                        := 'TRAJECTORY'
    TYPE.DATA                                   := 'INCREMENTAL.X'
    SLOPE.LEFT                                  := '0.0'
    SLOPE.RIGHT                                 := '0.0'
    SCALE.X                                     := '1.0'
    SCALE.Y                                     := '1.0'
    START.X                                     := '0.0'
    INCREMENT.X                                 := '1000.0'
    INTERPOLATION                               := 'CUBIC'
    DATA
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
      0.00000000000000E+00 0.00000000000000E+00 0.00000000000000E+00 0.0000000000
```

0.00000000000000E+00	0.00000000000000E+00	0.00000000000000E+00	0.000000000(
0.00000000000000E+00	0.00000000000000E+00	0.00000000000000E+00	0.000000000(
0.00000000000000E+00	0.00000000000000E+00	0.00000000000000E+00	0.000000000(
0.00000000000000E+00	0.00000000000000E+00	0.00000000000000E+00	0.000000000(
0.00000000000000E+00	0.00000000000000E+00	0.00000000000000E+00	0.000000000(
0.00000000000000E+00	0.00000000000000E+00	0.00000000000000E+00	0.000000000(
0.00000000000000E+00	0.00000000000000E+00	0.00000000000000E+00	0.000000000(
0.00000000000000E+00	0.00000000000000E+00	0.00000000000000E+00	0.000000000(
0.00000000000000E+00	0.00000000000000E+00	0.00000000000000E+00	0.000000000(
0.00000000000000E+00	0.00000000000000E+00	0.00000000000000E+00	0.000000000(
0.00000000000000E+00	0.00000000000000E+00	0.00000000000000E+00	0.000000000(

ENDDATA

```
FILE:  {AARDEMA.DADS3D.HMMWV.1037.HIGHCG.NATC}HMMUV_15MPH.INP

USER_INPUT FILE: HMMWV_15MPH.INP
TERRAIN: NATC Nevada Test Course May, 1987 Job# 2017-297
TIRE DATA: UMTRI (No Aligning Torque Data is available from UMTRI)

Roll Stiffness (lbs/rad) :
 14692.0
Fore-Aft Offset used to give some distance before entering terrain
 350.0
Vertical offset for each tire: (ZOFFSET(I),I=1,# of tires)
 13.38      13.38      13.38      13.38
Rotational Inertia of each wheel: (ROTINT(I),I=1,# of wheels)
 40.0       40.0       40.0       40.0
Run Flat Radius
 12.50
Run Flat Stiffness
10000.0
Run Flat Damping
  0.00
Trajectory Curve Name
TRAJECTORY
Speed Controller Command Vehicle Velocity:
264.00
Position error feedback gain PKP:
  0.0
Velocity error feedback gain PKV:
  0.0
Maximum output torque at each wheel @ 100% engine power TORMAX:
  0.0
Rotation Point about global Z to get new vehicle orientation
  0.0        0.0        0.0
Rotation Angle about global Z
  0.0
Lateral Force versus slip and vertical force - 24PSI - UMTRI data
   6    6
Slip Angle Data - 24 PSI - UMTRI data
  0.0         0.01745    0.03491    0.06981    0.1396     0.2793
Vertical Force Data - 24PSI - UMTRI data
  0.000    500.000    800.000   1700.000   2600.000   5000.000
Lateral Force Data - 24PSI - UMTRI data
  0.0        0.0        0.0        0.0        0.0        0.0
  0.0       84.500    157.500    271.000    367.500    416.500
  0.0      139.000    254.500    424.500    577.000    642.500
  0.0      277.500    511.000    880.500   1215.500   1378.000
  0.0      313.000    578.000   1042.000   1580.000   1958.000
  0.0      224.500    411.000    751.000   1397.500   2447.000
Lateral Force versus slip and vertical force - 24PSI - UMTRI data
   6    6
Slip Angle Data - 24 PSI - UMTRI data
  0.0         0.01745    0.03491    0.06981    0.1396     0.2793
Vertical Force Data - 24PSI - UMTRI data
  0.000    500.000    800.000   1700.000   2600.000   5000.000
Lateral Force Data - 24PSI - UMTRI data
  0.0        0.0        0.0        0.0        0.0        0.0
  0.0       84.500    157.500    271.000    367.500    416.500
```

```
   0.0       139.000    254.500    424.500    577.000    642.500
   0.0       277.500    511.000    880.500   1215.500   1378.000
   0.0       313.000    578.000   1042.000   1580.000   1958.000
   0.0       224.500    411.000    751.000   1397.500   2447.000
 Aligning Torque versus slip and vertical force - No Data from UMTRI
    2    2
 Slip Angle Data - No Data from UMTRI
   0.0        1.000
 Vertical Force Data - No Data from UMTRI
   0.000   20000.00
 Aligning Torque Data - No Data from UMTRI - Zero out the Torque
   0.0        0.0
   0.0        0.0
 Aligning Torque versus slip and vertical force - No Data from UMTRI
    2    2
 Slip Angle Data - No Data from UMTRI
   0.0        1.000
 Vertical Force Data - No Data from UMTRI
   0.000   20000.00
 Aligning Torque Data - No Data from UMTRI - Zero out the Torque
   0.0        0.0
   0.0        0.0
 GROUND SURFACE DATA: NATC Nevada Test Course May, 1987 Job# 2017-297
    2   72
 X(I), I=1,NX      (FORMAT 8F10.4)
 -108.0000  108.0000
 Y(I), I=1, NY (FORMAT 8F10.4)
    0.0000      2.52      84.12     128.28     132.96     174.84     176.76     219.60
   219.84     293.16     296.16     368.40     372.36     418.08     420.00     455.40
   457.32     523.56     527.76     592.56     598.20     675.00     675.36     730.08
   732.48     778.56     778.92     854.28     856.68     927.48     931.68     966.36
   966.60    1023.24    1026.24    1081.68    1082.04    1132.80    1138.32    1201.56
  1204.20    1236.96    1240.56    1276.68    1285.68    1378.44    1384.08    1460.40
  1462.68    1496.76    1500.72    1543.92    1544.16    1621.80    1625.28    1690.20
  1692.60    1760.40    1767.60    1805.40    1806.12    1864.44    1869.36    1946.88
  1951.20    2000.00    3000.00    4000.00    5000.00    6000.00    7000.00    8000.00
 Z(I),I=1,N
    0.0000     -0.02      -0.60       7.80       9.18      21.51      22.08      11.76
    11.72      -0.92      -1.44       8.04       8.87      18.44      18.84       9.72
     9.43      -0.57      -1.20      -0.72      -0.09       8.48       8.52      19.90
    20.40       8.76       8.72       0.15      -0.12       6.24       7.03      13.56
    13.51       2.39       1.80      -0.84      -0.83       0.68       0.84       9.82
    10.20      17.23      18.00       9.93       7.92      -0.11      -0.60       7.91
     8.16      13.54      14.16       7.08       7.05      -2.28      -2.04       2.47
     2.64      13.56      14.42      18.96      18.86      10.68      10.18       2.24
     1.80       1.00       1.00       1.00       1.00       1.00       1.00       1.00
 Z(I),I=1,N
     1.13       1.08      -0.60       7.00       7.80      16.92      16.62       9.88
     9.84      -0.12       0.27       9.57      10.08      14.40      14.08       8.12
     7.80      -2.52      -2.32       0.70       0.96       6.84       6.90      16.56
    16.29      11.20      11.16       0.12       0.40       8.52       9.00      14.72
    14.76       5.16       4.91       0.27       0.24       1.32       1.99       9.72
    10.40      18.84      18.80       9.60       8.73      -0.24       0.57      11.52
    11.90      17.52      16.73       8.09       8.04      -2.76      -3.24      -0.60
```

-0.21	10.83	12.00	16.59	16.68	8.93	8.28	1.08
0.68	1.00	1.00	1.00	1.00	1.00	1.00	1.00

APPENDIX F

STATIC ANALYSIS INPUT DATA FILE

```
FILE:  [AARDEMA.DADS3D.HMMWV.1037.REAR_SUSP.FORCE_XYZ]XYZFG_5000_JOINT.VB3
CREATE HEADER
THIS IS A MODEL OF THE RIGHT REAR SUSPENSION ELEMENTS
THE CHASSIS IS FIXED TO GROUND
-
THE SPHERICAL JOINT Z AXIS IS ALONG THE KINGPIN LINE
WHERE Z IS UPWARD AND X IS TO THE RIGHT
-
A CONSTANT X,Y,Z GLOBAL FORCE IS APPLIED TO THE WHEEL
TO DETERMINE THE FORCES IN THE OTHER ELEMENTS

ANALYSIS
CREATE SYSTEM.DATA
    UNITS                                   := 'ENG'
    ANALYSIS.TYPE                           := 'DYNAMIC'
    STARTING.TIME                           := '0.0'
    ENDING.TIME                             := '1.0'
    PRINT.INTERVAL                          := '0.05'
    GRAVITY.SEA.LEVEL                       := '386.400'
    X.GRAVITY                               := '0.0'
    Y.GRAVITY                               := '0.0'
    Z.GRAVITY                               := '-1.0'
    SCALE.GRAVITY.COEF                      := '1.0'
    MATRIX.OPERATIONS                       := 'SPARSE'
    REDUNDANCY.CHECK                        := 'TRUE'
    LU.TOL                                  := '1.0D-12'
    ASSEMBLY.TOL                            := '1.0D-3'
    BYPASS.ASSEMBLY                         := 'FALSE'
    OUTPUT.FILE                             := 'BOTH'
    REFERENCE.FRAME                         := 'GLOBAL'
    DEBUG.FLAG                              := 'TRUE'
UP
CREATE DYNAMIC.DATA
    REACTION.FORCES                         := 'TRUE'
    FORCE.COORDINATES                       := 'JOINT'
    PRINT.METHOD                            := 'INTERPOLATED'
    MAX.INT.STEP                            := '0.05'
    SOLUTION.TOL                            := '0.001'
    INTEGRATION.TOL                         := '0.0001'
UP
UP
CONSTRAINTS
CREATE DISTANCE.CONSTRAINT
    NAME                                    := 'RAD-ROD.RR'
    BODY.1.NAME                             := 'CHASSIS'
    BODY.2.NAME                             := 'WHEEL.RR'
    P.ON.BODY.1                             := ( 16.380, -161.980, 33.080 )
    P.ON.BODY.2                             := ( 32.327, -164.066, 30.405 )
    Q.ON.BODY.1                             := ( 16.380, -161.980, 34.080 )
    Q.ON.BODY.2                             := ( 32.327, -164.066, 31.405 )
    R.ON.BODY.1                             := ( 17.380, -161.980, 33.080 )
    R.ON.BODY.2                             := ( 33.327, -164.066, 30.405 )
    DISTANCE                                := '16.3037980237?3'
    NODE.1                                  := '0'
    NODE.2                                  := '0'
```

```
UP
UP
FORCE
CREATE TSDA
    NAME                          := 'DUMMY_TSDA_1'
    BODY.1.NAME                   := 'CHASSIS'
    BODY.2.NAME                   := 'ARM.LRR'
    SPRING.CONSTANT               := '0.0'
    FREE.LENGTH.SPRING            := '0.0'
    DAMPING.COEFFICIENT           := '0.0'
    ACTUATOR.FORCE                := '0.0'
    P.ON.BODY.1                   := ( 0.0, 0.0, 0.0 )
    P.ON.BODY.2                   := ( 0.0, 0.0, 0.0 )
    Q.ON.BODY.1                   := ( 0.0, 0.0, 1.0 )
    Q.ON.BODY.2                   := ( 0.0, 0.0, 1.0 )
    R.ON.BODY.1                   := ( 1.0, 0.0, 0.0 )
    R.ON.BODY.2                   := ( 1.0, 0.0, 0.0 )
    CURVE.SPRING                  := 'NONE'
    CURVE.DAMPER                  := 'NONE'
    CURVE.ACTUATOR                := 'NONE'
    NODE.1                        := '0'
    NODE.2                        := '0'
UP
CREATE TSDA
    NAME                          := 'DUMMY_TSDA_2'
    BODY.1.NAME                   := 'CHASSIS'
    BODY.2.NAME                   := 'ARM.LRR'
    SPRING.CONSTANT               := '0.0'
    FREE.LENGTH.SPRING            := '0.0'
    DAMPING.COEFFICIENT           := '0.0'
    ACTUATOR.FORCE                := '0.0'
    P.ON.BODY.1                   := ( 0.0, 0.0, 0.0 )
    P.ON.BODY.2                   := ( 0.0, 0.0, 0.0 )
    Q.ON.BODY.1                   := ( 0.0, 0.0, 1.0 )
    Q.ON.BODY.2                   := ( 0.0, 0.0, 1.0 )
    R.ON.BODY.1                   := ( 1.0, 0.0, 0.0 )
    R.ON.BODY.2                   := ( 1.0, 0.0, 0.0 )
    CURVE.SPRING                  := 'NONE'
    CURVE.DAMPER                  := 'NONE'
    CURVE.ACTUATOR                := 'NONE'
    NODE.1                        := '0'
    NODE.2                        := '0'
UP
CREATE TSDA
    NAME                          := 'DUMMY_TSDA_3'
    BODY.1.NAME                   := 'CHASSIS'
    BODY.2.NAME                   := 'ARM.LRR'
    SPRING.CONSTANT               := '0.0'
    FREE.LENGTH.SPRING            := '0.0'
    DAMPING.COEFFICIENT           := '0.0'
    ACTUATOR.FORCE                := '0.0'
    P.ON.BODY.1                   := ( 0.0, 0.0, 0.0 )
    P.ON.BODY.2                   := ( 0.0, 0.0, 0.0 )
    Q.ON.BODY.1                   := ( 0.0, 0.0, 1.0 )
```

```
     Q.ON.BODY.2                             := ( 0.0, 0.0, 1.0 )
     R.ON.BODY.1                             := ( 1.0, 0.0, 0.0 )
     R.ON.BODY.2                             := ( 1.0, 0.0, 0.0 )
     CURVE.SPRING                            := 'NONE'
     CURVE.DAMPER                            := 'NONE'
     CURVE.ACTUATOR                          := 'NONE'
     NODE.1                                  := '0'
     NODE.2                                  := '0'
UP
CREATE TSDA
     NAME                                    := 'SPRING.RR'
     BODY.1.NAME                             := 'CHASSIS'
     BODY.2.NAME                             := 'ARM.LRR'
     SPRING.CONSTANT                         := '2108.00'
     FREE.LENGTH.SPRING                      := '15.030'
     DAMPING.COEFFICIENT                     := '0.0'
     ACTUATOR.FORCE                          := '0.0'
     P.ON.BODY.1                             := ( 19.747, -174.865, 40.868 )
     P.ON.BODY.2                             := ( 21.385, -174.597, 28.935 )
     Q.ON.BODY.1                             := ( 19.747, -174.865, 41.868 )
     Q.ON.BODY.2                             := ( 21.385, -174.597, 29.935 )
     R.ON.BODY.1                             := ( 20.747, -174.865, 40.868 )
     R.ON.BODY.2                             := ( 22.385, -174.597, 28.935 )
     CURVE.SPRING                            := 'NONE'
     CURVE.DAMPER                            := 'NONE'
     CURVE.ACTUATOR                          := 'NONE'
     NODE.1                                  := '0'
     NODE.2                                  := '0'
UP
CREATE TSDA
     NAME                                    := 'SHOCK.RR'
     BODY.1.NAME                             := 'CHASSIS'
     BODY.2.NAME                             := 'ARM.LRR'
     SPRING.CONSTANT                         := '0.0'
     FREE.LENGTH.SPRING                      := '0.0'
     DAMPING.COEFFICIENT                     := '0.0'
     ACTUATOR.FORCE                          := '0.0'
     P.ON.BODY.1                             := ( 19.598, -174.865, 43.492 )
     P.ON.BODY.2                             := ( 21.415, -174.597, 29.259 )
     Q.ON.BODY.1                             := ( 19.598, -174.865, 44.492 )
     Q.ON.BODY.2                             := ( 21.415, -174.597, 30.259 )
     R.ON.BODY.1                             := ( 20.598, -174.865, 43.492 )
     R.ON.BODY.2                             := ( 22.415, -174.597, 29.259 )
     CURVE.SPRING                            := 'NONE'
     CURVE.DAMPER                            := 'NONE'
     CURVE.ACTUATOR                          := 'NONE'
     NODE.1                                  := '0'
     NODE.2                                  := '0'
UP
UP
JOINTS
CREATE REVOLUTE.JOINT
     NAME                                    := 'REV.LRR'
     BODY.1.NAME                             := 'CHASSIS'
```

```
    BODY.2.NAME                          := 'ARM.LRR'
    P.ON.BODY.1                          := ( 12.09, -170.77, 30.770 )
    P.ON.BODY.2                          := ( 12.09, -170.77, 30.770 )
    Q.ON.BODY.1                          := ( 12.09, -169.77, 30.770 )
    Q.ON.BODY.2                          := ( 12.09, -169.77, 30.770 )
    R.ON.BODY.1                          := ( 13.09, -170.77, 30.770 )
    R.ON.BODY.2                          := ( 13.09, -170.77, 30.770 )
    NODE.1                               := '0'
    NODE.2                               := '0'
UP
CREATE REVOLUTE.JOINT
    NAME                                 := 'REV.URR'
    BODY.1.NAME                          := 'CHASSIS'
    BODY.2.NAME                          := 'ARM.URR'
    P.ON.BODY.1                          := ( 18.195, -162.380, 39.655 )
    P.ON.BODY.2                          := ( 18.195, -162.380, 39.655 )
    Q.ON.BODY.1                          := ( 18.195, -161.380, 39.655 )
    Q.ON.BODY.2                          := ( 18.195, -161.380, 39.655 )
    R.ON.BODY.1                          := ( 19.195, -162.380, 39.655 )
    R.ON.BODY.2                          := ( 19.195, -162.380, 39.655 )
    NODE.1                               := '0'
    NODE.2                               := '0'
UP
CREATE SPHERICAL.JOINT
    NAME                                 := 'SPH.LRR'
    BODY.1.NAME                          := 'ARM.LRR'
    BODY.2.NAME                          := 'WHEEL.RR'
    P.ON.BODY.1                          := ( 30.965, -169.370, 26.120 )
    P.ON.BODY.2                          := ( 30.965, -169.370, 26.120 )
    Q.ON.BODY.1                          := ( 28.170, -169.370, 39.270 )
    Q.ON.BODY.2                          := ( 28.170, -169.370, 39.270 )
    R.ON.BODY.1                          := ( 44.115, -169.370, 28.915 )
    R.ON.BODY.2                          := ( 44.115, -169.370, 28.915 )
    NODE.1                               := '0'
    NODE.2                               := '0'
UP
CREATE SPHERICAL.JOINT
    NAME                                 := 'SPH.URR'
    BODY.1.NAME                          := 'ARM.URR'
    BODY.2.NAME                          := 'WHEEL.RR'
    P.ON.BODY.1                          := ( 28.170, -169.370, 39.270 )
    P.ON.BODY.2                          := ( 28.170, -169.370, 39.270 )
    Q.ON.BODY.1                          := ( 25.375, -169.370, 52.420 )
    Q.ON.BODY.2                          := ( 25.375, -169.370, 52.420 )
    R.ON.BODY.1                          := ( 41.320, -169.370, 42.065 )
    R.ON.BODY.2                          := ( 41.320, -169.370, 42.065 )
    NODE.1                               := '0'
    NODE.2                               := '0'
UP
UP
CREATE BODY
    NAME                                 := 'CHASSIS'
    CENTER.OF.GRAVITY                    := ( 0.585, -123.170, 63.064 )
    TYPE.ANGULAR.COORD                   := 'BRYANT'
```

```
ANGLE.1                      := '0.0'
ANGLE.2                      := '0.0'
ANGLE.3                      := '0.0'
FIXED.TO.GROUND              := 'TRUE'
MASS                         := '20.049'
INERTIA.XXL                  := '41300.0'
INERTIA.YYL                  := '13900.0'
INERTIA.ZZL                  := '52300.0'
INERTIA.XYL                  := '0.0'
INERTIA.XZL                  := '0.0'
INERTIA.YZL                  := '0.0'
XG.FORCE                     := '0.0'
YG.FORCE                     := '0.0'
ZG.FORCE                     := '0.0'
XL.TORQUE                    := '0.0'
YL.TORQUE                    := '0.0'
ZL.TORQUE                    := '0.0'
CURVE.XGF                    := 'NONE'
CURVE.YGF                    := 'NONE'
CURVE.ZGF                    := 'NONE'
CURVE.XLT                    := 'NONE'
CURVE.YLT                    := 'NONE'
CURVE.ZLT                    := 'NONE'
SIGN.EO                      := 'POSITIVE'
ANGULAR.UNITS                := 'DEGREES'
FLEXIBLE                     := 'FALSE'
SUPERELEMENT                 := 'FALSE'
UP
CREATE BODY
NAME                         := 'ARM.LRR'
CENTER.OF.GRAVITY            := ( 21.5275, -170.77, 28.445 )
TYPE.ANGULAR.COORD           := 'BRYANT'
ANGLE.1                      := '0.0'
ANGLE.2                      := '13.84'
ANGLE.3                      := '0.0'
FIXED.TO.GROUND              := 'FALSE'
MASS                         := '0.0932'
INERTIA.XXL                  := '1.0'
INERTIA.YYL                  := '1.0'
INERTIA.ZZL                  := '1.0'
INERTIA.XYL                  := '0.0'
INERTIA.XZL                  := '0.0'
INERTIA.YZL                  := '0.0'
XG.FORCE                     := '0.0'
YG.FORCE                     := '0.0'
ZG.FORCE                     := '0.0'
XL.TORQUE                    := '0.0'
YL.TORQUE                    := '0.0'
ZL.TORQUE                    := '0.0'
CURVE.XGF                    := 'NONE'
CURVE.YGF                    := 'NONE'
CURVE.ZGF                    := 'NONE'
CURVE.XLT                    := 'NONE'
CURVE.YLT                    := 'NONE'
```

```
      CURVE.ZLT                             := 'NONE'
      SIGN.EO                               := 'POSITIVE'
      ANGULAR.UNITS                         := 'DEGREES'
      FLEXIBLE                              := 'FALSE'
      SUPERELEMENT                          := 'FALSE'
   UP
   CREATE BODY
      NAME                                  := 'ARM.URR'
      CENTER.OF.GRAVITY                     := ( 23.1825, -165.875, 39.4625 )
      TYPE.ANGULAR.COORD                    := 'BRYANT'
      ANGLE.1                               := '0.0'
      ANGLE.2                               := '2.21'
      ANGLE.3                               := '0.0'
      FIXED.TO.GROUND                       := 'FALSE'
      MASS                                  := '0.0311'
      INERTIA.XXL                           := '1.0'
      INERTIA.YYL                           := '1.0'
      INERTIA.ZZL                           := '1.0'
      INERTIA.XYL                           := '0.0'
      INERTIA.XZL                           := '0.0'
      INERTIA.YZL                           := '0.0'
      XG.FORCE                              := '0.0'
      YG.FORCE                              := '0.0'
      ZG.FORCE                              := '0.0'
      XL.TORQUE                             := '0.0'
      YL.TORQUE                             := '0.0'
      ZL.TORQUE                             := '0.0'
      CURVE.XGF                             := 'NONE'
      CURVE.YGF                             := 'NONE'
      CURVE.ZGF                             := 'NONE'
      CURVE.XLT                             := 'NONE'
      CURVE.YLT                             := 'NONE'
      CURVE.ZLT                             := 'NONE'
      SIGN.EO                               := 'POSITIVE'
      ANGULAR.UNITS                         := 'DEGREES'
      FLEXIBLE                              := 'FALSE'
      SUPERELEMENT                          := 'FALSE'
   UP
   CREATE BODY
      NAME                                  := 'WHEEL.RR'
      CENTER.OF.GRAVITY                     := ( 38.815, -169.37, 29.735 )
      TYPE.ANGULAR.COORD                    := 'BRYANT'
      ANGLE.1                               := '0.0'
      ANGLE.2                               := '0.0'
      ANGLE.3                               := '-0.247'
      FIXED.TO.GROUND                       := 'FALSE'
      MASS                                  := '0.5046'
      INERTIA.XXL                           := '1.0'
      INERTIA.YYL                           := '1.0'
      INERTIA.ZZL                           := '1.0'
      INERTIA.XYL                           := '0.0'
      INERTIA.XZL                           := '0.0'
      INERTIA.YZL                           := '0.0'
      XG.FORCE                              := '2500.0'
```

```
    YG.FORCE                               := '2500.0'
    ZG.FORCE                               := '5000.0'
    XL.TORQUE                              := '0.0'
    YL.TORQUE                              := '-40887.5'
    ZL.TORQUE                              := '0.0'
    CURVE.XGF                              := 'NONE'
    CURVE.YGF                              := 'NONE'
    CURVE.ZGF                              := 'NONE'
    CURVE.XLT                              := 'NONE'
    CURVE.YLT                              := 'NONE'
    CURVE.ZLT                              := 'NONE'
    SIGN.EO                                := 'POSITIVE'
    ANGULAR.UNITS                          := 'DEGREES'
    FLEXIBLE                               := 'FALSE'
    SUPERELEMENT                           := 'FALSE'
UP
CREATE INITIAL.CONDITION
    NAME                                   := 'INIT.RR'
    BODY.1.NAME                            := 'WHEEL.RR'
    BODY.2.NAME                            := 'NONE'
    ELEMENT.NAME                           := 'NONE'
    TYPE.INITIAL.COND                      := 'Z'
    INITIAL.VALUE                          := '0.0'
    TIME.DERIVATIVE                        := '0.0'
    OMEGA.Y                                := '0.0'
    OMEGA.Z                                := '0.0'
    P.ON.BODY.1                            := ( 0.0, 0.0, 0.0 )
    P.ON.BODY.2                            := ( 0.0, 0.0, 0.0 )
    EXTRA.COORD                            := '0'
    ANGULAR.UNITS                          := 'DEGREES'
UP
*
```

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